

Prepared for:
USAID-SARI/Energy Program
www.sari-energy.org



Viability of Developing a Transmission System Interconnection between India and Sri Lanka

Technical Options and Investment Requirements

 **Nexant**

FEBRUARY 2002

**VIABILITY OF DEVELOPING A TRANSMISSION SYSTEM
INTERCONNECTION BETWEEN INDIA AND SRI LANKA**

TECHNICAL OPTIONS AND INVESTMENT REQUIREMENTS

For

United States Agency for International Development

Under

South Asia Regional Initiative for Energy

Prepared by

Mr. H.L. Tayal (Team Leader)

Mr. Sunil Ghose (Team Member)

Mr. Fernando D. Gabriel Rienzie (Team Member)

NEXANT

Acknowledgements

This paper could not have been written without the creative insights, technical inputs and suggestions provided by many talented and helpful people. Many organisations in the power sector have provided much of the detailed information in this report, and further have helped to develop and critique the key ideas it presents. The study team wishes to thank the following institutions for their support provided particularly during the preparation and data collection stages of the project.

- Powergrid Corporation of India Ltd.
- Power Trading Corporation of India Ltd.
- Central Electricity Authority, India
- Ceylon Electricity Board, Sri Lanka
- National Physical Planning Department, Sri Lanka
- Ceylon Petroleum Corporation, Sri Lanka
- National Aquatic Research Agency (NARA), Sri Lanka
- ABB, Sweden & New Delhi

We are especially indebted to the Powergrid Corporation of India Ltd. and Ceylon Electricity Board for their support are providing invaluable guidance on the ideas contained in the paper. Many useful suggestions, both substantive and editorial, were provided by Committee members and staff. Despite of all this useful assistance, the views and opinions expressed herein, and all remaining errors, are solely those of the author.

The study team is grateful to the USAID for its continuous technical, financial and other forms of support, which immensely contributed to the successful completion of the study.

Contents

Section	Page
Executive Summary	iv
1 Background, Purpose, and Scope	1-1
2 Transmission and Generation Systems Review	2-1
2.1 Existing and Planned Transmission Systems.....	2-1
2.1.1 Transmission System in Sri Lanka	2-1
2.1.2 Transmission System in India	2-2
2.2 Existing Generation Capacity and Load	2-3
2.2.1 Sri Lanka Power Generation and Load	2-3
2.2.2 India's Power Generation and Load	2-4
2.3 Supply/Demand Situation to 2012	2-5
2.3.1 Supply/Demand Situation in Sri Lanka	2-5
2.3.2 Supply/Demand Situation in India.....	2-7
2.4 Potential for Power Exchange.....	2-8
3 Transmission Interconnections.....	3-1
3.1 Definition of Alternatives	3-1
3.1.1 Rationale	3-1
3.1.2 Alternative MAI-HVDC	3-3
3.1.2.1 Variation MAI – HVDC 1: Bipolar HVDC Interconnection....	3-4
3.1.2.2 Variation MAI – HVDC 2: Monopolar HVDC Interconnection	3-4
3.1.2.3 Variation MAI – HVDC 3: Bipolar HVDC Interconnection	
with all overhead DC	3-5
3.1.3 Alternative TPI-HVDC	3-6
3.1.3.1 Variation TPI-HVDC 1: HVDC: Bipolar HVDC	
Interconnection	3-6
3.1.3.2 Variation TPI-HVDC 2: HVDC: Monopolar HVDC	
Interconnection	3-7
3.1.4 Alternative MPI-HVDC.....	3-8
3.1.4.1 Variation MAI-HVDC 1: HVDC: Bipolar HVDC	
Interconnection	3-8
3.1.4.2 Variation TPI-HVDC 2: HVDC: Monopolar HVDC	
Interconnection	3-9
3.1.5 Alternative MAI-BBDC.....	3-10
3.2 Technical Assessment.....	3-11
3.2.1 Assessment of Alternative MAI-HVDC.....	3-11
3.2.2 Assessment of Alternative TPI-HVDC.....	3-12
3.2.3 Assessment of Alternative MPI-HVDC.....	3-12
3.2.4 Assessment of Alternative MAI-BBDC	3-12

Section	Page
3.2.5 Concluding Observation	3-13
4 Economic Assessment of Options	4-1
4.1 Investment Requirements.....	4-1
4.1.1 Bipolar HVDC Interconnections.....	4-2
4.1.2 Monopolar HVDC Interconnections.....	4-3
4.1.3 AC Interconnection.....	4-3
4.2 Economic Assessment of the Alternative	4-4
4.2.1 Levelized Transmission Costs.....	4-5
4.2.2 Assessment Based on Cost of Electricity.....	4-6
4.2.2.1 Wholesale Energy Tariff in India	4-6
4.2.2.2 Wholesale Energy Tariff in Sri Lanka	4-6
4.2.2.3 Expected Delivered cost of energy in Sri Lanka	4-6
4.3 Conclusions.....	4-7
5 Conclusions and Recommendations.....	5-1
5.1 Conclusions	5-1
5.2 Recommendations.....	5-2
6 Next Steps.....	6-1
7 Bibliography	7-1
Appendix A HVDC Features.....	A-1
Appendix B Grid Map of Southern Region of India	B-1
Appendix C Grid Map of Sri Lanka	C-1

Figures	Page
2-1 Sri Lanka's Current Installed Capacity.....	2-4
2-2 Sri Lanka's Annual Generation in Year 2000.....	2-4
2-3 India's Current (2001) Supply/Demand Situation.....	2-5
2-4 India's Planned Expansion and Projected Demand Through 2012.....	2-7
3-1 Alternative A1 Schematic Diagram.....	3-4
3-2 Alternative A2 Schematic Diagram.....	3-5
3-3 Alternative A3 Schematic Diagram.....	3-6
3-4 Alternative B1 Schematic Diagram.....	3-7
3-5 Alternative B2 Schematic Diagram.....	3-8
3-6 Alternative C1 Schematic Diagram.....	3-9
3-7 Alternative C2 Schematic Diagram.....	3-10
3-8 Alternative D Schematic Diagram.....	3-11
4-1 Estimated Investment Costs of Alternatives.....	4-2
4-2 Levelized Transmission Costs of Each Alternative.....	4-5
4-3 Levelized Transmission Charge.....	4-5
4-4 Expected Delivered Cost of Energy in Sri Lanka.....	4-7
 Tables	 Page
2-1 Sri Lanka's current demand/supply situation.....	2-4
2-2 Generating Plants under Construction or Planned in Sri Lanka.....	2-6
2-3 Sri Lanka Base Load Forecast – 2000.....	2-6
2-4 India's Supply/Demand Scenario Through 2012.....	2-7
4-1 Estimated Investment Costs for Alternatives.....	4-1
4-2 Relative Advantages and Disadvantages of the Alternatives.....	4-4
4-3 Relative Overall Advantages and Disadvantages of the Alternatives...	4-8

Executive Summary

PURPOSE OF THE STUDY

The purpose of this study is to examine and assess the possibilities for interconnecting the transmission systems of India and Sri Lanka. The objective of such a transmission interconnection would be to facilitate bilateral power exchange between the two countries. This interconnection could provide significant benefits to the economies of the two countries through closer cooperation on power exchange, enhanced system reliability, improved security and diversity of supply, increased economic efficiency in system operation, reduced environmental impacts, and lower costs to consumers. This interconnection could also help attract private sector investment to the power sector.

The study is set out in two phases. The two-phase approach provides the opportunity to screen a multitude of possible transmission interconnections and narrow-down the number of alternatives to three or four for a more detailed assessment. The content of this report, is an initial technical and economic assessment of number of possible interconnections. The more detailed technical and economic assessment of a few selected alternatives will be the subject of the detailed Feasibility Study, which will follow the concurrence of the concerned stakeholders.

The study is intended to be the first step in developing the project concept and in bringing this concept to reality. It is expected to serve as the basis for further technical and economic assessments and for identification of institutional requirements needed to support the project. Accordingly, the study will identify, additional technical assistance that may be needed to move the project to the next stage in the development process.

ASSESSMENT OF PROJECT ALTERNATIVES

Four basic possible alternative transmission interconnection configurations that would provide for bilateral power exchange between India and Sri Lanka were identified and assessed. These basic alternatives also have a number of variations, which have resulted in a total of eight alternatives. The availability of several connecting substations in the two countries and the potential of using Alternating current(AC) and Direct current (DC)transmission technologies provided the basis for the eight alternative configurations.

The substations that could be beneficial for the proposed project in India are Madurai and Tuticorin in the State of Tamil Nadu, and Anuradhapura and Puttalam in Sri Lanka.

The alternative transmission technologies considered are 'High Voltage DC (HVDC)' and 'High Voltage AC (HVAC) with back-to-back DC'. The HVDC technology has two variations – bipolar and monopolar. At a conceptual level, a bipolar connection may be viewed as consisting of two parallel paths of power flow, each path carrying half of the total power. A monopolar connection may be viewed as consisting of one path of power flow carrying full power. In the 'HVAC with back-to-back DC' technology, a double-circuit (d/c) configuration has been considered, as a d/c configuration is a standard cost-effective method. In this technology, the back-to-back DC feature is considered. This feature eliminates the frequency matching problem between the Indian and Sri Lankan grids.

Thus the four basic alternatives are:

- **Alternative 'MAI-HVDC':** Madurai-Anuradhapura Interconnection using HVDC;
- **Alternative 'TPI-HVDC' :** Tuticorin-Puttalam Interconnection using HVDC;
- **Alternative 'MPI-HVDC':** Madurai-Puttalam Interconnection using HVDC;
- **Alternative 'MAI-BBDC':** Madurai-Anuradhapura Interconnection using HVAC with back-to-back DC.

PRINCIPAL FINDINGS

The principal findings of this study are:

- The concept of the transmission interconnection between India and Sri Lanka with a view to transferring power appears to face no technical barriers.
- Transfer of power from India would provide Sri Lanka with a power supply option in addition to its own generation expansion options.
- A 400kV transmission interconnection has been looked at, which has a transfer capability of up to about 1,000 MW. In this report, the economics of 500 MW initial transfer of power has been looked at.
- An initial economic assessment indicates investment requirements that range from about \$116 million to \$175 million for the various alternatives.
- Indicative levelized transmission charge attributable to the alternatives ranges from 0.6 cents per kWh to 0.9 cents per kWh for transfers of 500 MW at 85% plant load factor.
- Tuticorin-Puttalam HVDC and Madurai-Anuradhapura Back-to-Back DC alternatives are the most expensive. These alternatives do not offer any additional technical advantage over the others. Thus, these alternatives will not be further considered.
- A preferred alternative will be identified in Phase II of this Pre-Feasibility study.

COST DATA

Option	Investment Cost US \$ M	Wheeling Charges US \$ Cents / Kwh
MAI – HVDC	116 / 153	0.6 / 0.62
TPI – HVDC	153 / 175	0.78 / 0.9
MPI – HVDC	138 / 156	0.68 / 0.8
MAI – BBDC	140	0.67

For transfer of 500 MW of power, delivered cost of energy to Sri Lanka ranges from 6.5 to 8 cents / Kwh against their expected own generation cost ranging from 7 to 9 cents / Kwh.

BENEFITS OF THE PROPOSED INTERCONNECTION

- Potential for export of surplus base load power.
- Creates opportunities for joint investments.
- Improves supply profile (base / peaking)
- Initial initiative on regional co-operation would lead a path towards much more diversified trading potential.

RECOMMENDATIONS AND NEXT STEPS

Both India and Sri Lanka are facing a growing gap between power demand and supply. However, India's power system is very large, and its North Eastern and Eastern regions have surplus power and the neighboring countries also have significant hydro potential. This surplus energy should be available to support power exports from India to export power to Sri Lanka. The proposed transmission interconnection between the two countries would provide advantages to both the systems in terms of optimizing the installed capacity by way of utilizing the diversity in peak demand, sharing spinning reserves and also optimizing the overall generation mix.

To facilitate the detailed Feasibility study, it is recommended that a Working Committee consisting of stakeholders representing India and Sri Lanka be established. This Committee would:

- Ensure that a detailed project report for the World Bank and the Asian Development Bank that meets all the requirements for developing, financing, and implementing the proposed transmission interconnection is produced.
- Ensure that the environmental issues associated with this project are addressed by the Environmental Assessment Team to be formed.
- Liaise with energy ministries and other government and private sector entities of the two countries to develop and implement the proposed transmission interconnection;
- Direct the related technical assistance that is being provided under the SARI/Energy project that could support implementation of the proposed project.
- Activities that could be supported under the SARI/Energy project include:
 - Reviewing the energy supply/demand balance; confirm the amount and cost of power available for power exchange under the recommended alternative;
 - Identifying and recommending favoured alternative for establishing open transmission access, fair pricing and conditions of service for inclusion in a bilateral transmission services agreement;
 - Reviewing legal and regulatory requirements to support development of the proposed transmission interconnection;
 - Assistance in establishing a regulatory regime; and
 - Support development of an initial environmental impact assessment.

A broad view of the technical and economic aspects of the transmission interconnection was taken in this Study. Further detailed assessments would be needed to demonstrate the viability of such a project and to establish competitiveness against other supply options. The detailed assessments in the next phase of the study would include:

- Evaluation of the economic and financial viability of the transmission interconnection as a power supply option for Sri Lanka
- Evaluation of the HVDC application consisting of
 - Bipolar vs. monopolar
 - Under-sea vs. overhead
- Preliminary load flow studies to confirm operational benefits and system losses
- Refine capital cost estimates for establishing financial requirements

- Commercial/Financial/Legal/Regulatory issues for global developments in Regional Power Cooperation to facilitate development of the project.
- Desirability of overhead transmission towers across Palk Strait.
- Evaluation of the location of interconnecting substation in Sri Lanka. The delivered cost of imported power from India would depend on the transmission distance of load center from the interconnecting substation.

In the detailed Feasibility Study, the technical features of the project would be developed in much greater details and a detailed capital and operating cost estimate would be generated. For that purpose, the following specific activities would be required:

- Detailed survey for right of way, telegraphic right of way, environmental impact statement, forest clearances etc.
- Detailed soil investigations for both the sea and land in both the countries in order to firm up the configuration of the inter-regional link.
- Detailed equipment and materials requirement for the project to support a reliable cost estimate.

In addition, all institutional issues need to be examined at a greater depth.

The details of the present analysis, including technical and economic assessment of alternatives and basic data and assumptions are provided in the body of this report. A map showing the conceptual configuration for the alternative Indo-Sri Lanka Transmission Interconnections is shown below.



Legend

Overhead Transmission Line



Submarine Cable Transmission Line



Figure : Indo-Sri Lanka Transmission Alternatives

INTRODUCTION

The idea of establishing a transmission interconnection between India and Sri Lanka is not new. The idea was first considered in the late 1970's by Professor Zablonksi in Sri Lanka (no reference document was available). Recently, USAID has asked Nexant to re-visit the idea as a part of the inter-regional initiative under the Sari/Energy program. The rationale was that an interconnection of the electric grids of these two countries would provide opportunities to enhance system reliability and provide the ability to exchange power among these countries. Furthermore, as the countries are in close geographic proximity, such an interconnection would not require a large investment and would pose the fewest technical challenges. Thus, this study was conceived to provide an initial proof of concept.

Due to the close proximity of the two countries, an electrical interconnection could be developed with minimal technical challenges and with reasonable investment.

Currently with the absence of any interconnection, no power exchange between the two countries takes place. In discussions with the principal stakeholders in each country, there was a general support for the concept of a proposed interconnection. All stakeholders believed that the technical issues should not present a significant barrier; rather it was the non-technical issues such as commercial operation and financing that appeared to pose a greater challenge. Additionally, since the perception is that Sri Lanka would be a net importer of power, views were also expressed regarding the overall cost/benefit of the interconnection as compared to new generation additions in Sri Lanka. These concerns are not unique, to this region. Globally, interconnected grids are already in operation in Southern Africa and Northern Europe, and regional grids are proposed or under development in the Baltics, Balkans, and Central and South America. Thus, sufficient precedents exist that have proven that non-technical barriers can be resolved to mutual benefit.

In reviewing the proposed interconnection, the underlying premises for this assessment were that:

- The interconnection must benefit both the countries; and
- The interconnection could be implemented relatively quickly with minimal technical, investment, and institutional requirements.

In this regard, it was essential to examine a realistic timeframe under which such a project could materialize. The consensus was that, given the conditions and the needs of each country and the time needed to construct such an interconnection, it would be unrealistic to consider a project implementation time-frame shorter than five years. Thus a 5-year implementation period was used.

BACKGROUND

India has a total installed capacity of about 100,000 MW with an all-India average plant load factor of about 60%. It has a peak demand of about 75,000 MW and the peak demand shortage is around 11.3%. India is following the path of restructuring its power sector, and is catalyzing developments in all areas of power generation, transmission, and distribution. The main development priority in India is to meet rapidly increasing industrial and commercial needs and to expand the population-access to electricity under public financial constraints. Therefore, an important approach of the program is to facilitate private sector participation in generation and transmission to ensure adequate competition in order to capture investment and operating efficiencies, which are gained through private ownership. The goal of the Government of India (GOI) is to achieve a total generating capacity addition of about 110,000 MW during 2002-2012. Thus, development of the transmission system is required to match the concomitant development of bulk power generation for transmitting the generated power to load centers.

Sri Lanka has a total installed capacity of 1,838 MW with an average plant load factor of about 53%. Of this, 1,150 MW is generated from hydro stations and the balance is basically from thermal stations. The maximum observed peak demand is 1,405 MW and the average peak demand is about 1,350 MW. Sri Lanka's energy supply depends heavily on rainfall as the hydro plants have the dominant contribution on energy as well as capacity. Sri Lanka experienced a power shortage in 2000 and in 2001 of about 300 MW due to a delay in thermal additions planned to meet the hydro shortfall. Ceylon Electricity Board (CEB), the main power authority in Sri Lanka, managed to obtain short-term power at a higher cost from diesel generating units. But later in July 2001, the short-term power was terminated, as it was economically prohibitive. Power cuts, which ranged from half an hour to three hours, were imposed through November 2001 to trim the peak. The use of energy-intensive appliances such as commercial air conditioning were banned forcing commercial establishments to generate their own power by their stand-by generators.

To consider the possibility of power interconnection between India and Sri Lanka, some successful examples of international interconnections may be studied. There are however only few examples of international interconnection between the power grids of the developing countries. In spite of this, the example of Southern Africa Power Pool (SAPP) may be considered as an example.

As the power systems of developing countries expand, and in particular when market reforms take place in the electric power sector, it becomes increasingly economical to interconnect with neighboring countries to benefit from the pooling of resources. There are many political, economic, contractual and legal issues that need to be addressed when such international interconnections are established.

Establishing a new interconnection between two separated power systems involves much more than just a new transmission line between the two closest substations. There are several issues that have to be addressed:

- Amount of power that needs to be exchanged in each direction
- Availability of suitable terminus substations for the interconnection

- Reliability requirements to ensure all standards are met
- Compatibility of the frequencies of the two grids
- Appropriate method of transmission interconnection (under-sea cable vs. an overhead line)
- High voltage DC vs. AC with back-to-back DC

The national electric grids of India and Sri Lanka are in reasonably close proximity. Any project conceived to enhance system reliability through exchange of power would call for reasonable investment with very few technical challenges with the latest developments on the technological front. The present study is aimed at providing the first proof of concept of establishing a transmission interconnection between the two countries.

OBJECTIVES OF THIS STUDY

The objectives of the study are to define and frame the requirements and conditions needed to develop a transmission interconnection combined with an initial estimate of associated net benefits. To achieve these objectives a preliminary assessment of the potential to develop a regional power system interconnection between India and Sri Lanka was conducted. This was accomplished by reviewing the existing infrastructure and by proposing alternative transmission system approaches, which could be implemented with minimal environmental restrictions. Two areas were emphasized in the concept development phase: technical requirements and economics of power transfer.

Technical requirements – Based upon consideration of the existing grids in each country and plans for upgrades, alternative system configurations were defined and their technical requirements assessed. In developing these alternatives, consideration was given to potential power exchange opportunities; projected power system supply and demand scenarios; power generation options; capacity and compatibility of the grids; and load dispatch between these countries.

Economics of power transfer – Based on the technical requirements, the first order indicative investment requirements and associated economics of the concept were assessed by estimating projected energy costs and prospective transmission costs. Other associated benefits and costs also were identified and defined.

The objectives of this study are to define the conditions needed to develop a transmission interconnection; present an initial estimate of associated costs and benefits; and identify issues that need further review and resolution.

BASIC APPROACH

In order to have an opportunity to evaluate the proof of concept, a two-phase approach has been considered for this study. The two-phase approach provides the opportunity to screen a multitude of possible alternative transmission interconnections and narrow-down the number of alternatives to three or four for a more detailed assessment. The content of this report, is an initial technical and economic assessment of the multitude of possible interconnections. The more detailed technical and economic assessment of a few selected alternatives will be the

subject of the detailed Feasibility Study, which will follow the concurrence of the concerned stakeholders.

While this study entails several tasks, some in greater detail, the first phase will focus on preliminary technical and economic assessment of interconnection for power exchange between the two countries. The second phase would evaluate both the technical and economic viability in greater detail as well as outline the environmental, operational, legal, regulatory and institutional aspects of the proposed interconnection.

The approach taken in this first order assessment has been to consider the following:

- Identify locations in India and Sri Lanka for the potential terminus points for interconnection, and type of link and transmission capacity based on the load generation scenarios of both the power systems. This analysis includes a review of installed capacity, type of generation, future expansion, and load variation during the day, future growth in power demand.
- Approximate length of the transmission lines indicative capital costs, time schedule for establishing the link, and technical specification for the HVDC cable and other equipment required.
- Justification of the projects including its utilization and cost-benefit analysis.
- Outline the tasks for completing the detailed feasibility study

The focus of this study is to assess the potential for developing a power transmission interconnection between India and Sri Lanka.

In this section, the basis for power exchange between India and Sri Lanka over the next ten years is addressed by examining the following in each country:

- Existing and planned transmission system (Section 2.1)
- Existing generation capacity and load (Section 2.2)
- Power supply/demand (Section 2.3)
- Potential for power exchange (Section 2.4)

As will be discussed in Section 3, the substations at Madurai and Tuticorin in the Indian State of Tamil Nadu, and Anuradhapura and Puttalam in Sri Lanka are the alternative terminus points for interconnecting the two countries. These locations are referenced in this overview.

2.1 Existing and Planned Transmission Systems

The transmission alternatives for interconnecting the grids in India and Sri Lanka will depend on existing and planned transmission system developments in each country. Accordingly, the situation review begins with a survey of the transmission systems in each country.

2.1.1 Transmission System in Sri Lanka

The transmission system in Sri Lanka is owned and operated by Ceylon Electricity Board (CEB). There is no private sector participation in the transmission sector, although there is private sector participation in the generation sector through independent power producers (IPPs).

The Sri Lankan transmission system is interconnected in one national grid. The system consists of an integrated network of 132 kV and 220 kV lines covering the main load centers of the country. Existing east-west double circuit 220 kV lines interconnect Kelanitissa on the west coast with Rantembe at the center of the country. In the north-south direction, existing double circuit 220 kV lines interconnect Kotmale at the center of the country with New Anuradhapura located at the north-central part of the country. The north-south and the east-west lines are also connected to form an interconnected national grid. Double circuit 220 kV lines also interconnect Kotugoda with Muthuragawella and Biyagama, and Dehiwala with Pannipitiya. All of these latter lines are in the vicinity of major load centers around Colombo. The total length of the 220kV lines is about 315 route kilometers.

An extensive network of 132 kV lines covers the majority of the country. Chunnakam substation is the northernmost point, and Matara is the southernmost point. The total route length of the 132kV transmission lines exceeds 1,400 kilometers.

Sri Lanka's transmission system is being upgraded to improve its power distribution capability and evacuate power from planned power plants.

A number of transmission lines are planned in Sri Lanka to be installed by 2005. The major line is the double circuit 220 kV Puttalam-New Chilaw-Veyangoda-Kotugoda line. This line

will be used to evacuate power from the proposed power station near Puttalam and connect to the national grid. The route length of the line will be approximately 110 km.

2.1.2 Transmission System in India

India's power/transmission system is divided into five distinct regions – North, West, East, South, and Northeast. With the exception of East and Northeast, all other regions are currently operating independently. Synchronous interconnections currently do not exist between these regions. The East and the Northeast are connected through synchronized alternating current (AC) links.

The existing operational and planned inter-regional links over the next five years are listed below.

Existing inter-regional links:

HVDC Links:

West to North with transfer capability of 500 MW
West to South with transfer capability of 1,000 MW
East to South with transfer capability of 500 MW

AC Links:

West to East with transfer capacity of 450 MW
East to South with transfer capacity of 200 MW
West to South with transfer capacity of 300 MW
North to East with transfer capacity of 200 MW
West to North with transfer capacity 200 MW
East to Northeast with transfer capacity of 1,000 MW

The total existing inter-regional transfer capacity is 4,350 MW. By the end of year 2002 the cumulative inter-regional transfer capacity is expected to be about 4,850 MW.

Planned inter-regional links in next five years (10th Five-Year Plan ending in 2007):

HVDC Links:

East to North with transfer capacity of 3,000 MW
East to South with transfer capacity of 2,000 MW

AC Links:

East to West with transfer capacity of 2,000 MW
East to North with transfer capacity of 2,000 MW

India's total transmission lines under operation include:

3,136 circuit km HVDC
42,000 circuit km 400 kV
212,000 circuit km 220/132 kV

Currently 400 kV is the backbone of India's transmission system. In the Eastern region, a triple circuit 400 kV line is under construction connecting Tala HEP in Bhutan and Siliguri substation in India. Another double circuit 400 kV line is also under construction connecting

Siliguri with Purnia in the State of Bihar. These lines will evacuate up to 1,000 MW from the Tala HEP for transfer to the Indian grid.

In the Eastern region, 220 kV is the primary transmission system linking Bongaigaon (Assam), Siliguri (West Bengal), and Purnia (Bihar). This link would provide the major power exchange route among India, Bangladesh, Nepal, and Bhutan.

Power Grid Corporation of India Ltd. is responsible for the development and operation of the interstate grid. Power Grid Corporation is currently seeking private sector participation in the development of the national grid.

India's transmission system is being upgraded to interconnect its five regional grids and to increase power imports.

2.2 Existing Generation Capacity and Load

2.2.1 Sri Lanka's Power Generation and Load

Until 1996, Sri Lanka's electricity demand was met by the hydro and thermal generating plants owned by Ceylon Electricity Board. Since then, the private sector has also participated in power generation. The existing generating system is still predominantly owned by CEB with about 95 percent of total generation. The remaining 5 percent is owned by various independent power producers (IPPs).

Sri Lanka has an installed generating capacity of 1,838 MW and a peak demand of 1,405 MW. Total annual generation during the year 2000 was approximately 6,700 GWh.

Sri Lanka's installed capacity of 1,838 MW consists of about 1,150 MW of hydropower, 685 MW of thermal power and 3 MW of renewable power. Although the installed capacity of the hydro plants constitutes more than 62 percent of the total installed capacity, the gross generation from these plants account for only about 48 percent of the total due to the low availability of the hydro plants. These effects are illustrated in Figures 2-1 and 2-2. The overall availability of all the generating plants has been estimated at about 55 to 60 percent.

Sri Lanka has a total hydro potential of about 2,000 MW, more than half of which has already been harnessed. Further exploitation is proving to be uneconomical. Thus thermal generation is the choice for the future, which has been doubled since 1996. The year 2001 demand and supply situation is shown in Table 2-1.

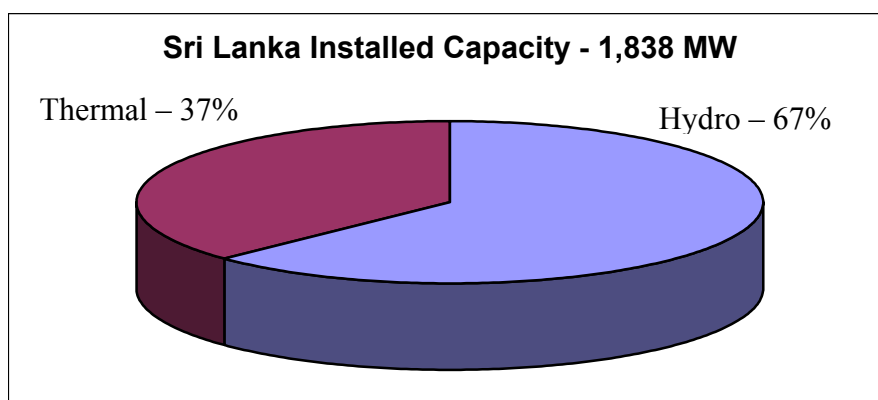


Figure 2-1 Sri Lanka's Current Installed Capacity

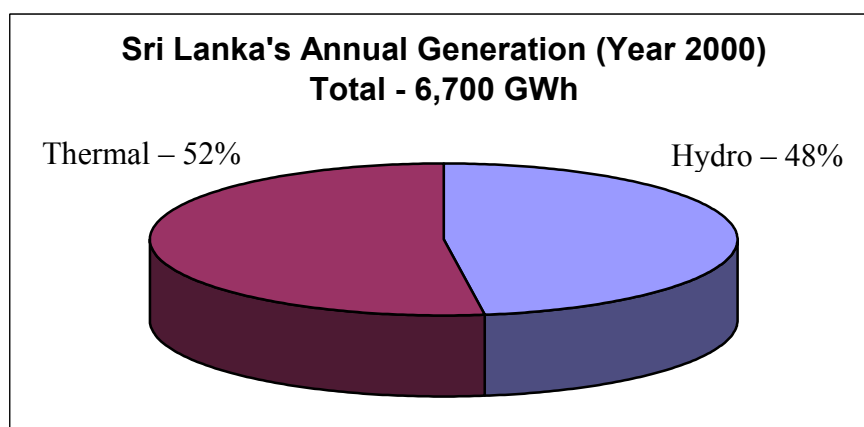


Figure 2-2 Sri Lanka's Annual Generation in Year 2000

Table 2-1 Sri Lanka's demand/supply situation for 2001*

Present installed capacity	1,838 MW
Available capacity	Ranged from 1,100 MW to 1,500 MW
Max. Observed Demand	1,405 MW
Average Peak Demand	1,350 MW
* Source – CEB, Sri Lanka	

2.2.2 India's Power Generation and Load

India's power generation capacity is much larger than that of Sri Lanka. The Indian electricity market is segmented into five distinct regions. The total installed capacity of all the regions combined is approximately 100,000 MW and the total peak demand is approximately 75,050 MW. Due to low plant load factor, which varies from 40 percent to 75 percent, there is a large shortfall in available capacity. Three of the five regions currently have capacity deficits while the Eastern and Northeastern regions have surplus capacity. The current surplus/deficit situation of the regions is shown in Figure 2-3. The Eastern and

Northeastern regions are shown together because they are interconnected and the Northeastern region has a very low demand.

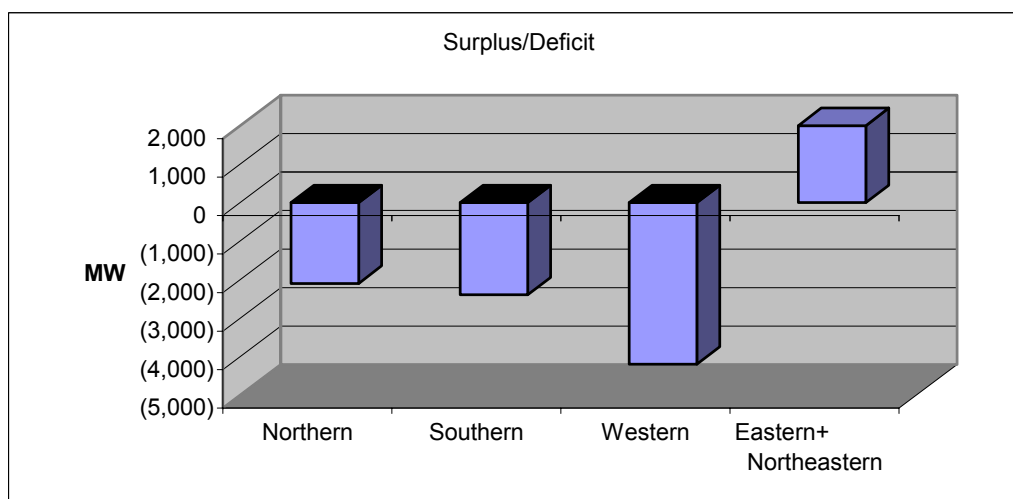


Figure 2-3 India's Current (2001) Supply/Demand Situation

The combined Eastern and Northeastern regions have an estimated 2,000 MW surplus while each of the Northern and Southern regions have deficits of about 2,200 MW and 2,700 MW, respectively. The Western region has a deficit of about 4,500 MW. As discussed in the preceding section, the interconnection with the Western region, the HVDC interconnection with the Southern region, and the HVDC interconnection with the Northern region now under development and/or construction will allow transfer of power from the surplus regions to the deficit regions by direct transfer or by displacement.

2.3 Supply/Demand Situation to 2012

For the purposes of this study, the time horizon of five to ten years (2007-2012) is used to gauge the market potential for developing a cross-border transmission interconnection. This is a period long enough to develop and construct a power system interconnection between the two countries. Set out below is a review of the prospective supply/demand situation in the two countries. This review is taken to estimate the available capacity that could be exchanged through the proposed interconnection. It may be pointed out that the supply projections are based on available information including planned additions that may be delayed, while demand is usually based on trended estimates that do not address potential or unmet demand. Accordingly, the projected generation requirements may be greater than those discussed below.

2.3.1 Supply/Demand Situation in Sri Lanka

As mentioned earlier, Sri Lanka's economically exploitable hydro potential is essentially developed with further exploitation other than mini/micro hydro proving to be uneconomic. Thus, thermal plants based on coal and petroleum based fuels are being introduced into the Sri Lankan generating system. The generating plants, which are either under construction or planned to be brought on line by the year 2014, are listed in Table 2-2.

Table 2-2: Generating Plants under Construction or Planned in Sri Lanka*

	Plant	MW	Expected Commissioning Year
1	Kelanitissa Combined Cycle (funded by JBIC)	100	2001
2	Kelanitissa Combined Cycle (AES)	100	2002
3	Medium-term Diesel Plants	2x20	2002/3
4	Kelanitissa Combined Cycle (funded by JBIC)	50	2003
5	Kelanitissa Combined Cycle (AES)	50	2003
6	Kerawalapitiya Combined Cycle	300	2003/4
7	Kukule Hydro	70	2004
8	Coal Steam West Coast	300	2006
9	Upper Kotmale Hydro	150	2007
10	Coal Steam West Coast	300	2008
11	Gas Turbine Plant	35	2009
12	Coal Steam West Coast	300	2010
13	Coal Steam West Coast - Trincomalee	300	2011
14	Gas Turbine Plant	105	2012
15	Coal Steam West Coast - Trincomalee	300	2013
16	Gas Turbine Plant	210	2014

* Source – CEB, Sri Lanka

In addition to the above, several plants totaling 178.5 MW are approaching their end of life and will be retired during this time frame. These include 2x22 MW Kelanitissa Oil Steam Plant, 4x18 MW Sapugaskanda Diesel Plant, 2x20 MW Medium-term Diesel Plant, and 22.5 MW Lakdanavi Diesel Plant.

In the year 2000, Ceylon Electricity Board developed a 'Base Load Forecast' for Sri Lanka through the year 2012 (Table 2-3), in which the peak demand is forecast to exceed 2,200 MW by the year 2007 and to exceed 3,200 MW by the year 2012. This demand may be met fully by the planned generation (Table 2-2) or partly by the planned generation and partly by the proposed import from India as discussed in the section below.

Table 2-3 Sri Lanka Base Load Forecast – 2000

Year	Demand, GWh	Generation, GWh	Peak, MW
2002	6,209	7,374	1,531
2003	6,381	7,525	1,562
2004	6,967	8,196	1,701
2005	7,620	8,923	1,852
2006	8,342	9,757	2,025
2007	9,118	10,639	2,208
2008	9,892	11,543	2,396
2009	10,684	12,467	2,588
2010	11,505	13,425	2,786
2011	12,374	14,439	2,997
2012	13,306	15,526	3,223

2.3.2 Supply/Demand Situation in India

India's Eleventh Five Year Plan calls for planned additions of more than 100,000 MW. However, based on past experiences it is unlikely that all the planned additions will come on line as scheduled, and as a result, peak demand shortfall is expected to persist in some regions. However, Eastern and North Eastern regions will continue to have excess capacity. India's transmission expansion plan once completed will be able to transfer up to 30,000 MW and is designed to enable the excess power to be transported to the deficit regions. In addition, India's generation expansion plan calls for import of power from neighboring countries in the amount of about 1,150 MW, which could start during the time period 2002 – 2006.

India's planned generation expansion and projected demand scenario in 2012 is shown in Table 2-4 and Figure 2-4.

Table 2-4 India's Supply/Demand Scenario Through 2012*

Region	Present Installed Capacity MW	Planned Capacity Addition By 2012, MW	Projected Installed Capacity in 2012, MW	Projected Demand in 2012 MW
Northern	27,200	25,000	52,200	49,000
Southern	25,000	35,000	60,000	42,000
Western	30,000	30,000	60,000	46,000
Eastern + Northeastern	17,200	21,000	38,200	19,000
Total	99,400	111,000	210,400	156,000

Source – PGC & CEA, India

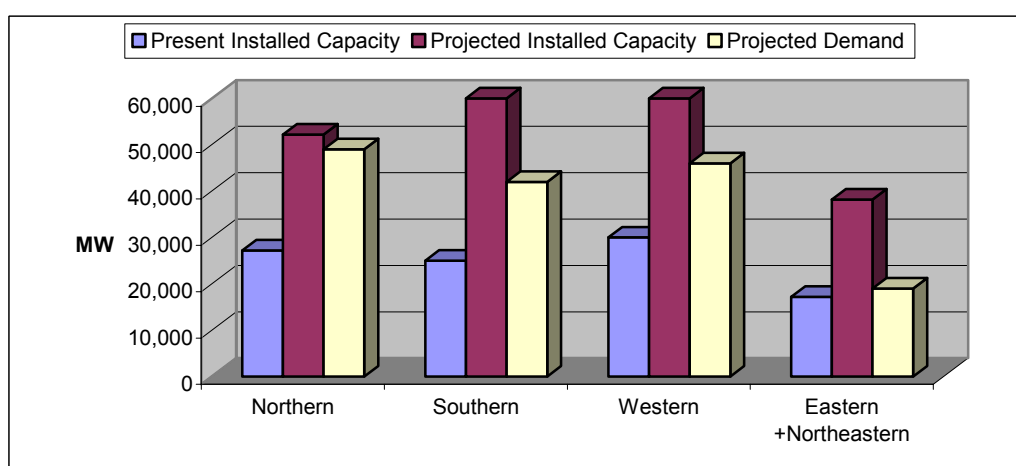


Figure 2-4 India's Planned Expansion and Projected Demand Through 2012

Supply/Demand Situation in Tamil Nadu. As has been discussed in Section 3, it is proposed that export of power for Sri Lanka be tapped from the national grid in the State of Tamil Nadu. Thus the supply and demand situation in Tamil Nadu is reviewed below.

Tamil Nadu State Electricity Board's (TNEB) current total available capacity is of the order of 7,500 MW of which about 5,500 MW is generated from its own power stations and about 2,000 MW is obtained from a central sector allocation. Tamil Nadu's peak demand is about 8,000 MW and is expected to increase to about 9,000 MW by 2007, and to about 12,000 MW by 2012. Current project proposals add up to a total installed capacity of about 15,000 MW by 2012. Of this, IPP proposals are expected to amount to about 12,000 MW. Tamil Nadu would also benefit from the expanded ability to transfer power from other regions of India, as well as from neighboring countries after completion of the national grid.

Tamil Nadu has been relatively successful in implementing IPP projects. Current reform of the state's electricity sector will help attract private investment to IPP's as will development of an export market for new generation. The availability of an export market in Sri Lanka will help mitigate the risk of developing IPP projects in Tamil Nadu and increase the likelihood that IPP development will take place. By building one plant to serve two markets, one internal to India and one external, an IPP could reduce the risk associated with project development. IPP developers also offer a potential source of investment for the proposed interconnection, as they may be interested in investing in the transmission system as a way to ensure an adequate market for their power and an opportunity to gain entry into another regional market. Moreover, Tamil Nadu can support Development of IPPs as a means of meeting domestic demand with any capacity developed in excess of domestic needs made available for export. In this way, India can meet its own power needs, earn additional foreign reserves and contribute to the development of regional markets and economies.

2.4 POTENTIAL FOR POWER EXCHANGE

The supply and demand situation of the two countries suggests that there is a potential for power exchange between these countries both in near term (year 2006-2007) as well as longer term (year 2012 and beyond). Currently, the Southern Region of India has a peak demand deficit of about 2,700 MW. There were plans for large capacity additions in the past but the plans did not materialize due to the poor financial health of the state electricity boards. However, due to recent power sector reforms, the supply situation is likely to improve in the near future, and accordingly within the next decade, a significant amount of power is expected to be added. The State of Tamil Nadu in the Southern Region has a large potential for LNG-based and lignite-based generating plants. Large numbers of IPPs are showing keen interest in putting up new generating stations, and negotiations are taking place with the concerned authorities. Sri Lanka presently has an installed capacity of 1,838 MW. The country anticipates a peak demand of more than 3,200 MW by the year 2012. Sri Lanka has exhausted her economically-exploitable hydro resources and the country does not have any indigenous fuel sources. Ceylon Electricity Board is exploring capacity addition in the near future using imported fuel with the help of IPPs. With such a scenario in perspective, both the countries would benefit from an exchange of power.

In the long term, there is even more potential for bilateral trade in general and power exchange in specific. Sri Lanka's National Physical Planning Department has proposed a long term policy that calls for a "Trade Highway" across the Palk Strait between India and Sri Lanka. Thus, with proper intent and commitment, the availability of power supply in both India & Sri Lanka can be boosted towards a higher security.

Further, the Eastern Region of India currently has a surplus of about 2,000 MW. With the planned capacity addition and reforms under way, the region is expected to have a surplus of about 10,000 MW by 2012. Power Grid of India has a massive expansion plan underway with the ultimate aim of the formation of a national grid, including inter-regional links, to wheel power from one region to the other.

With respect to the availability of exportable power from Sri Lanka to India, it would depend on the available generation in Tamil Nadu, the cost of generation in Sri Lanka and load diversity between Sri Lanka and the State of Tamil Nadu. Since Sri Lanka has no internal resources either in hydro (untapped), coal, oil, or gas, it depends completely on imported fuel, for new generating capacity which would tend to make generation cost high relative to the generation cost in India. This will be further evaluated in detailed feasibility study.

In emergencies or non-peaking periods, it should be possible to export power to India on a regional cooperation arrangement basis provided there is a political will on the part of both the countries.

In this section, the range of possibilities for transmission interconnection between India and Sri Lanka based on technical and economic requirements is reviewed. The need for establishing an interconnection between places separated by sea (Palk Strait) has been the primary consideration in identifying the range of possibilities. The interconnection has two objectives: First, the interconnection would enhance the reliability and system security of both the countries through the diversity of sources of supply, ability to provide assistance in times of emergencies, and sharing of reserve requirements. Second, the interconnection could facilitate the development of energy exchange between the two countries.

The proposed transmission interconnection would contribute to system reliability and security of supply and facilitate development of energy exchange between India and Sri Lanka.

3.1 DEFINITION OF ALTERNATIVES

3.1.1 RATIONALE

In developing the proposed alternative interconnections, consideration was given to the following factors:

- Existing and planned generating capacity in each country
- Existing and planned transmission systems in each country
- Time frame for development; and
- Technical and operational factors.

The rationale of this approach is that the alternatives under consideration would be consistent with the development plans in each country.

Taking into consideration the time necessary for design, permitting, and construction of transmission facilities, it is reasonable to expect that a transmission expansion project would be able to be in place within about a five-year period. This is also consistent with the supply/demand review presented in the previous section that suggests that power for export could be available in India and potentially in Sri Lanka as well by 2006-2007.

A number of alternative parameters contributed to identifying the multitude of alternative transmission interconnections:

- Number of possible interconnecting locations (substations) in both India and Sri Lanka
- Number of possible power transmission technologies
- Type of possible transmission connections across the sea

Interconnection Locations

There are two locations in India and two locations in Sri Lanka suitable for locating the terminus points for the interconnection. Madurai and Tuticorin are the two locations in India in the State of Tamil Nadu. Anuradhapura and Puttalam are the locations in Sri Lanka.

There is an existing 400/220kV substation in Madurai, while a 400/220kV substation is planned in Tuticorin before the year 2005. In Sri Lanka, there is an existing 132kV substation in Puttalam. However, Sri Lanka's transmission expansion plan embodies a 220kV substation each in Anuradhapura and in Puttalam, and 220kV transmission lines connecting these substations with the major load centers of the country. The substation and the transmission lines are planned to be built by the year 2005.

Transmission Technologies

Two power transmission technologies were considered: alternating current (AC) with back-to-back DC and direct current (DC).

AC With Back-to-Back DC Technology. An AC interconnection is the most commonly used technology. Generally, an AC interconnection is associated with the problem of matching the frequencies of two connecting grids if the two grids either have widely different frequencies or if the frequencies fluctuate widely in one or both the grids. The grids in India and Sri Lanka have a similar situation because the frequency fluctuation of the India's Southern Region power supply is large. To overcome this problem, an AC interconnection supplemented with DC is considered. This type of interconnection is called 'Back-to-Back DC', in which power is transmitted over AC lines from one substation to another. Before delivering power to the other substation, the AC power is first converted to DC and then immediately re-converted, i.e., inverted to AC. This conversion and re-conversion (or inversion) process electrically isolates the two substations thereby eliminating the frequency fluctuation problem.

HVDC Technology. In the high voltage DC (HVDC) technology, power is transferred in the form of direct current. HVDC is generally more expensive than AC. However, since the losses in a DC transmission line is much less than in an AC line, HVDC is the preferred choice for long distance power transmission.

In the HVDC technology, a converter station at one connecting substation (say for example, Madurai in India) and an inverter station at the other connecting substation (say for example, Puttalam in Sri Lanka) are needed. At the converter station, AC power is converted to DC. The power is then transmitted over a DC line to the other station, where the power is inverted back to AC. This method isolates one grid from the other thus eliminating the need for frequency matching between the two grids.

HVDC technology offers two configurations – bipolar and monopolar. At a conceptual level, a bipolar connection may be viewed as consisting of two parallel paths of power flow, each path carrying half of total power. A monopolar connection may be viewed as consisting of one path of power flow carrying full power. Both configurations have been considered.

Type of Possible Transmission Connections Across the Sea

Two possibilities exist for the interconnection across the sea: 1) under-sea cable, and 2) overhead conductor using transmission towers. In the case of AC with Back-to-Back DC, a major problem in using the under-sea cable is the prohibitive loss of power associated with the rather long distance of 30 km across Palk Strait. Because of this problem, the 'under-sea cable' alternative is not considered for the AC with Back-to-Back DC technology.

Similar to the AC connection, two possibilities exist for the HVDC interconnection for the portion across the sea: 1) under-sea cable, and 2) overhead conductor using transmission towers. The HVDC interconnection would not encounter any frequency fluctuation problem. In addition, power loss with the under-sea cable is much less compared to AC. Thus, both under-sea cable and overhead conductor alternatives have been considered for HVDC.

Alternative Transmission Interconnections

Given the above parameters, the following four basic alternatives are developed and reviewed in this report (Map in Executive Summary shows the geographic configuration of the alternatives):

- **Alternative 'MAI-HVDC'** : Madurai-Anuradhapura Interconnection using HVDC;
- **Alternative 'TPI-HVDC'** : Tuticorin-Puttalam Interconnection using HVDC;
- **Alternative 'MPI-HVDC'** : Madurai-Puttalam Interconnection using HVDC;
- **Alternative 'MAI-BBDC'** : Madurai-Anuradhapura Interconnection using AC with back-to-back DC.

For the Alternatives **MAI-HVDC**, **TPI-HVDC**, and **MPI-HVDC**, the following variations were considered:

1. Bipolar interconnection
2. Monopolar interconnection.

3.1.2 ALTERNATIVE MAI-HVDC: MADURAI-ANURADHAPURA INTERCONNECTION VIA MANNAR USING HVDC

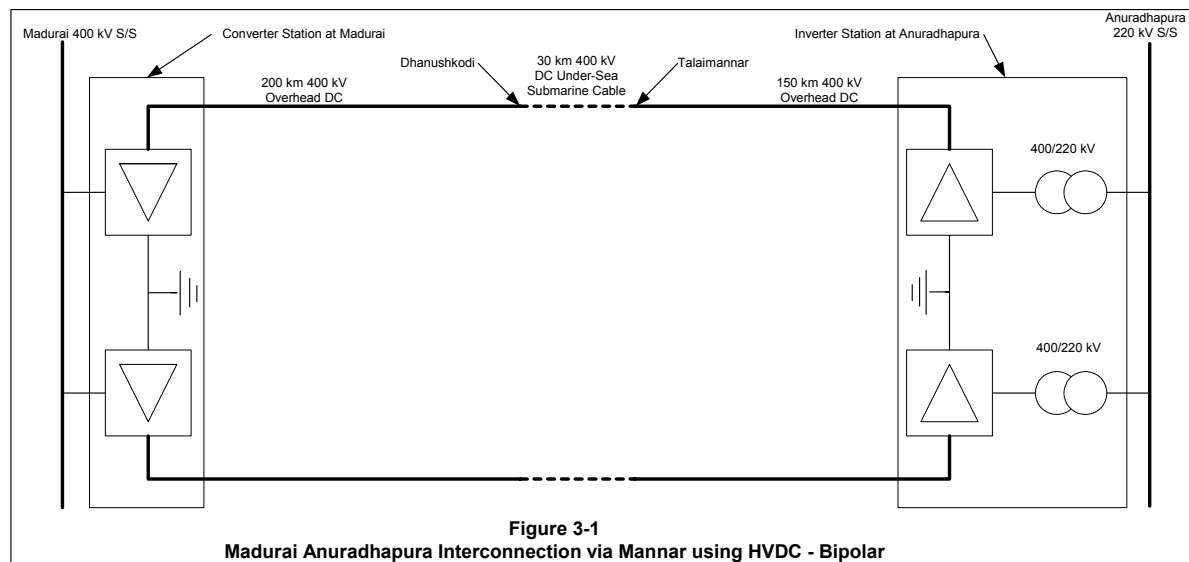
This interconnection involves a relatively short sea length. In this alternative, the Madurai substation in the State of Tamil Nadu is the terminus point in India, and Anuradhapura substation is the terminus point in Sri Lanka. The width of sea portion between these two terminus points is about 30 km between Dhanushkodi in Tamil Nadu and Talaimannar in Sri Lanka.

This Alternative includes three variations, which are outlined below. The first would use a bipolar HVDC line. The second would use a monopolar HVDC line. In each of the above two variations, under-sea cable is proposed. In the third variation, an overhead DC connection is proposed across Palk Strait. The details of each of these alternatives are outlined below and are represented in the associated schematic diagrams.

3.1.2.1 VARIATION MAI-HVDC1: BIPOLAR HVDC INTERCONNECTION

Figure 3-1 shows the line diagram for Variation 1, which would use a bipolar interconnection. Implementation of this alternative would require the following:

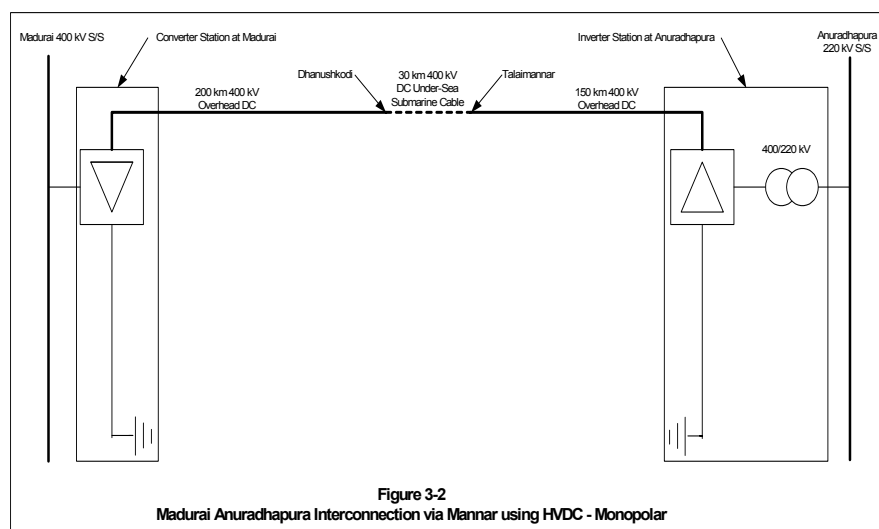
- A bipolar converter station adjacent to the Madurai 400 kV substation. The converter station will include two 250 MW converters and associated ancillary equipment
- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- An under-sea HVDC (submarine cable) transmission line from Dhanushkodi to Talaimannar (30 km)
- An overhead HVDC transmission line from Talaimannar to Anuradhapura (150 km)
- A bipolar inverter station adjacent to the Anuradhapura 220 kV substation. The inverter station will include two 250 MW inverters and associated ancillary equipment;
- Two 400/220 kV transformers and two feeder lines from these transformers to the 220 kV Anuradhapura substation.



3.1.2.2 VARIATION MAI-HVDC2: MONOPOLAR HVDC INTERCONNECTION

Figure 3-2 shows the line diagram for Variation 2, which would use a monopolar interconnection. Implementation of this alternative would require the following:

- A monopolar converter station adjacent to the Madurai 400 kV substation. The converter station will include one 500 MW converter and all associated ancillary equipment;
- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- An under-sea HVDC (submarine cable) transmission line from Dhanushkodi to Talaimannar (30 km)

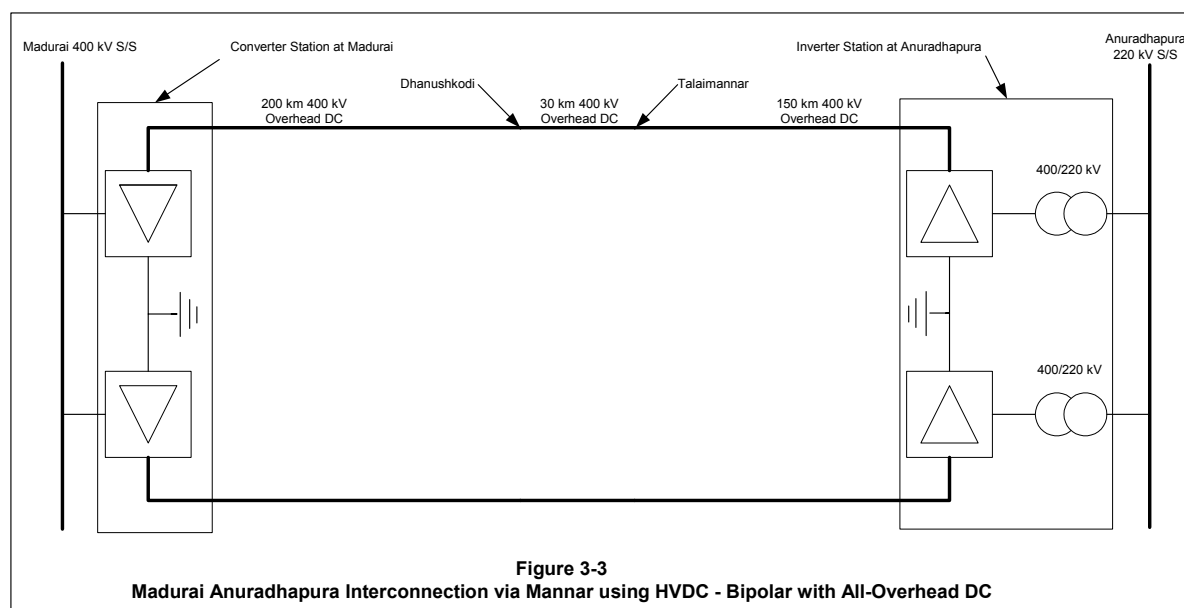


- An overhead HVDC transmission line from Talaimannar to Anuradhapura (150 km)
- A monopolar inverter station adjacent to the Anuradhapura 220 kV substation. The inverter station will include one 500 MW inverter and all associated ancillary equipment;
- One 400/220 kV transformer and one feeder line from this transformer to the 220 kV Anuradhapura substation.

3.1.2.3 VARIATION MAI-HVDC 3: BIPOLAR HVDC INTERCONNECTION WITH ALL-OVERHEAD DC

Figure 3-3 shows the line diagram for Variation 3, which would also use a bipolar interconnection similar to Variation 1. The difference between Variations 1 and 3 is that Variation 1 incorporates an under-sea cable over Palk Strait, whereas Variation 3 incorporates an overhead conductor with transmission tower. Surveys and satellite pictures of Palk Strait show that the stretch of the sea between Dhanuskodi and Talaimannar is generally very shallow, and is dotted with many small islands every two or so kilometers. These features of the strait would facilitate construction of towers for overhead transmission and do not appear to pose any unusual problems. Implementation of this alternative would require the following:

- A bipolar converter station adjacent to the Madurai 400/220 kV substation. The converter station will include two 250 MW converters and associated ancillary equipment;
- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- An overhead HVDC transmission line from Dhanushkodi to Talaimannar (30 km)
- An overhead HVDC transmission line from Talaimannar to Anuradhapura (150 km)
- A bipolar inverter station adjacent to the Anuradhapura 220 kV substation. The inverter station will include two 250 MW inverters and associated ancillary equipment;
- Two 400/220 kV transformers and two feeder lines from these transformers to the 220 kV Anuradhapura substation.



3.1.3 ALTERNATIVE TPI-HVDC: TUTICORIN-PUTTALAM HVDC INTERCONNECTION

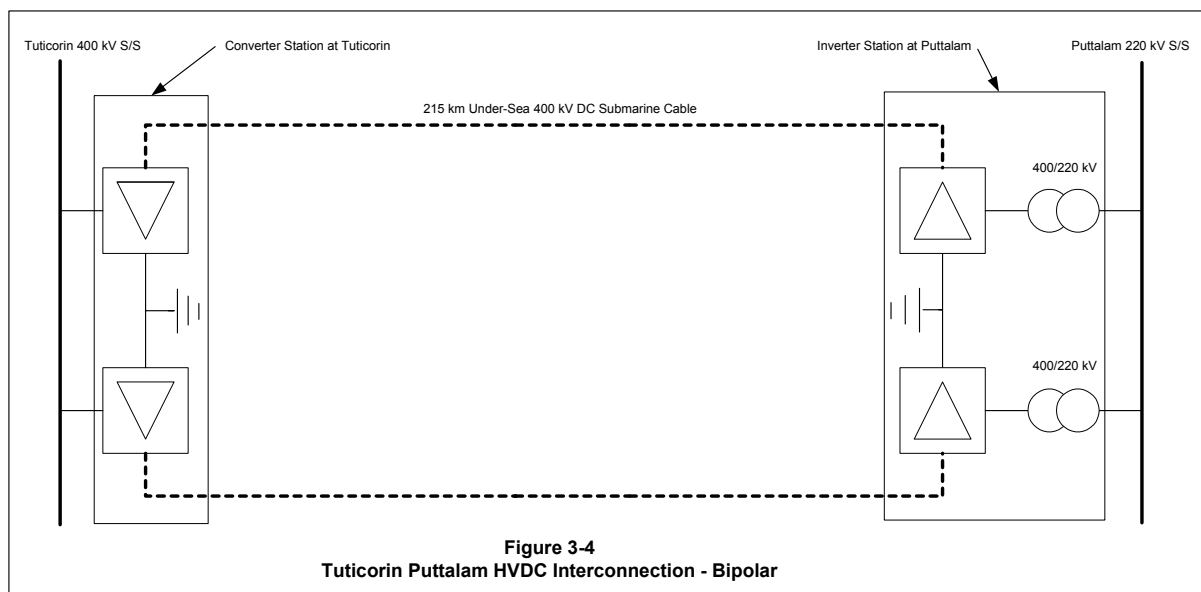
The interconnection Alternative **TPI-HVDC** involves a relatively long sea width. In this alternative, the Tuticorin substation in the State of Tamil Nadu is the terminus point in India and Puttalam substation is the terminus point on the west coast of Sri Lanka. The width of sea between these two terminus points is about 215 km. The entire transmission length is under the sea.

Alternative **TPI-HVDC** includes two variations, which are outlined below. The first would use a bipolar HVDC line and the second variation would use a monopolar HVDC line. The details of each of these two alternatives are outlined below and are represented in the associated schematic diagrams.

3.1.3.1 VARIATION TPI-HVDC 1: BIPOLAR HVDC INTERCONNECTION

Figure 3-4 shows the line diagram for **Variation 1**, which would use a bipolar interconnection. Implementation of this alternative would require the following:

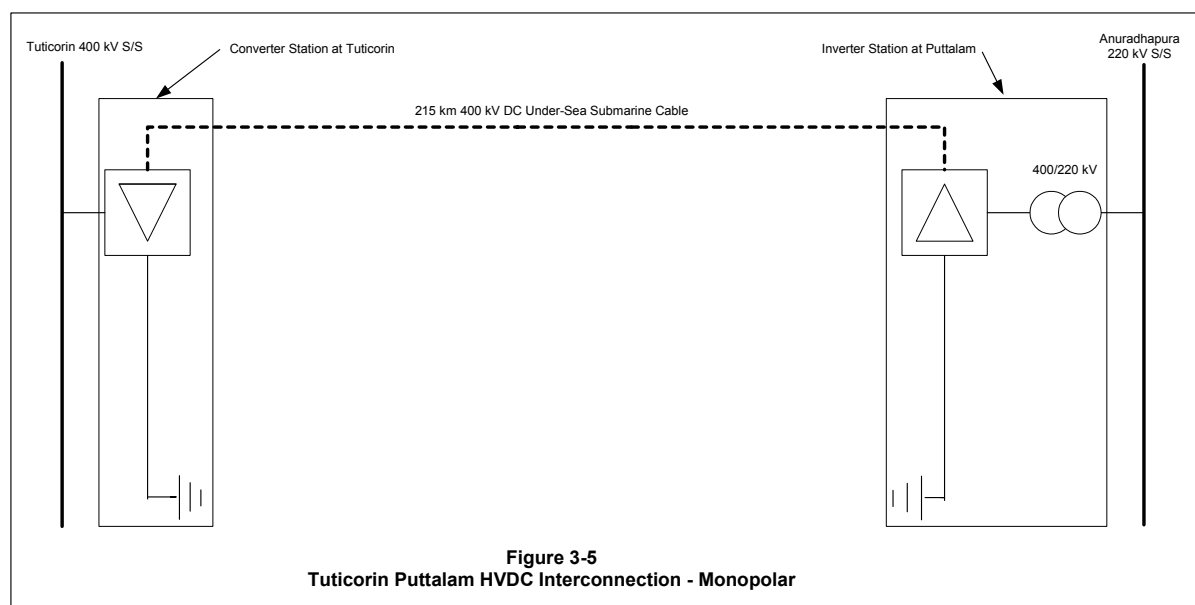
- A bipolar converter station adjacent to the Tuticorin 4000 kV substation. The converter station will include two 250 MW converters and all associated ancillary equipment;
- An under-sea HVDC (submarine cable) transmission line from Tuticorin to Puttalam (215 km)
- A bipolar inverter station adjacent to the Puttalam 220 kV substation. The inverter station will include two 250 MW inverters and associated ancillary equipment;
- Two 400/220 kV transformers and two feeder lines from these transformers to the 220 kV Puttalam substation.



3.1.3.2 VARIATION TPI-HVDC 2: MONOPOLAR HVDC INTERCONNECTION

Figure 3-5 shows the line diagram for **Variation 2**, which would use a monopolar interconnection. Implementation of this alternative would require the following:

- A monopolar converter station adjacent to the Tuticorin 220 kV substation. The converter station will include one 500 MW converter and all associated ancillary equipment;
- An under-sea HVDC (submarine cable) transmission line from Tuticorin to Puttalam (215 km)
- A monopolar inverter station adjacent to the Puttalam 220 kV substation. The inverter station will include one 500 MW inverter and all associated ancillary equipment;
- One 400/220 kV transformer and one feeder line from this transformer to the 220 kV Puttalam substation.



3.1.4 ALTERNATIVE MPI-HVDC: MADURAI-PUTTALAM INTERCONNECTION USING HVDC

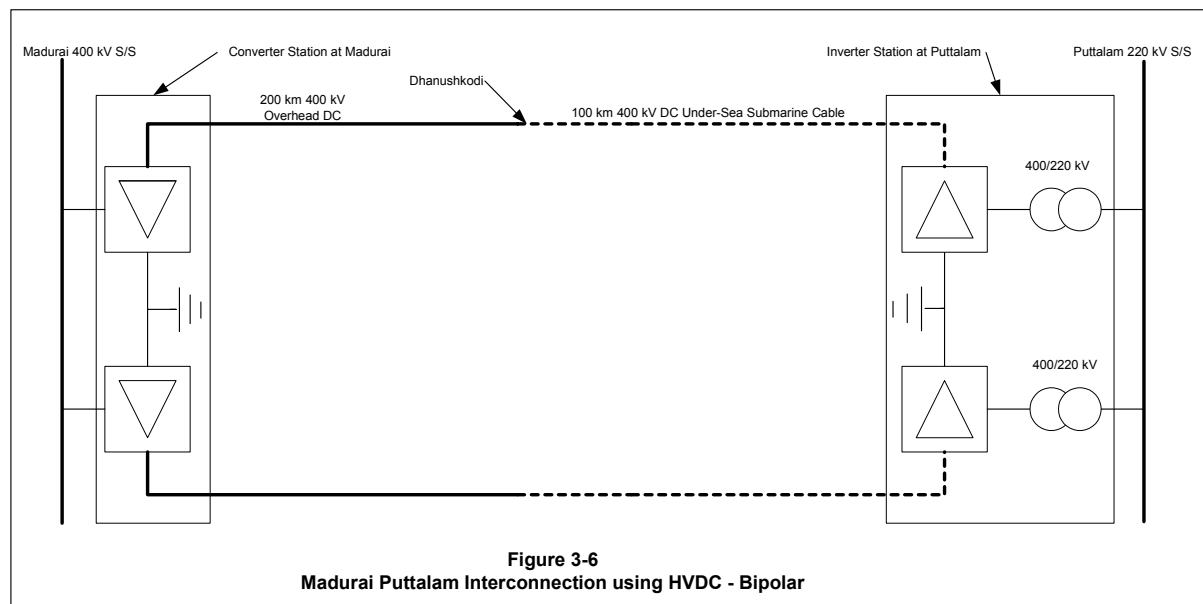
The interconnection Alternative MPI-HVDC involves a medium sea length. In this alternative, the Madurai substation in the State of Tamil Nadu is the terminus point in India and Puttalam substation on the west coast is the terminus point in Sri Lanka. The width of sea portion between these two terminus points is about 100 km. In this alternative, the transmission line consists of an overhead line from Madurai to Dhanushkodi, a sea route from Dhanushkodi to Kalputiya on the west coast of Sri Lanka, and an overhead line from Kalputiya to Puttalam.

Alternative MPI-HVDC includes two variations, which are outlined below. The first, Variation 1, would use a bipolar HVDC line and the second, Variation 2, would use a monopolar HVDC line. The details of each of these two alternatives are outlined below and are represented in the associated schematic diagrams.

3.1.4.1 VARIATION MPI-HVDC 1: BIPOLAR HVDC INTERCONNECTION

Figure 3-6 shows the line diagram for **Variation 1**, which would use a bipolar interconnection. Implementation of this alternative would require the following:

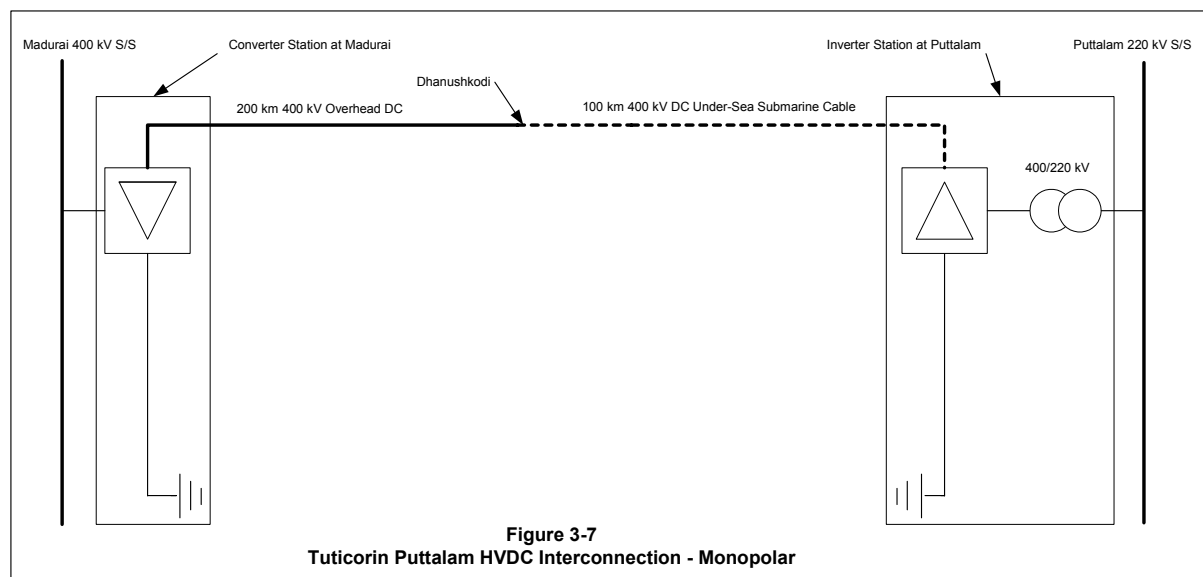
- A bipolar converter station adjacent to the Madurai 220 kV substation. The converter station will include two 250 MW converters and all associated ancillary equipment;
- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- A twin-cable under-sea HVDC (submarine cable) transmission line from Dhanushkodi to Kalputiya (100 km)
- An overhead HVDC transmission line from Kalputiya to Puttalam (25 km)
- A bipolar inverter station adjacent to the Puttalam 220 kV substation. The inverter station will include two 250 MW inverters and associated ancillary equipment;
- Two 400/220 kV transformers and two feeder lines from these transformers to the 220 kV Puttalam substation.



3.1.4.2 VARIATION MPI-HVDC 2: MONOPOLAR HVDC INTERCONNECTION

Figure 3-7 shows the line diagram for **Variation 2**, which would use a monopolar interconnection. Implementation of this alternative would require the following:

- A monopolar converter station adjacent to the Madurai 220 kV substation. The converter station will include one 500 MW converter and all associated ancillary equipment;
- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- An under-sea HVDC (submarine cable) transmission line from Dhanushkodi to Kalputiya (100 km)
- An overhead HVDC transmission line from Kalputiya to Puttalam (25 km)
- A monopolar inverter station adjacent to the Puttalam 220 kV substation. The inverter station will include one 500 MW inverter and associated ancillary equipment;
- One 220 kV transformer and one feeder lines from this transformer to the 220 kV Puttalam substation.



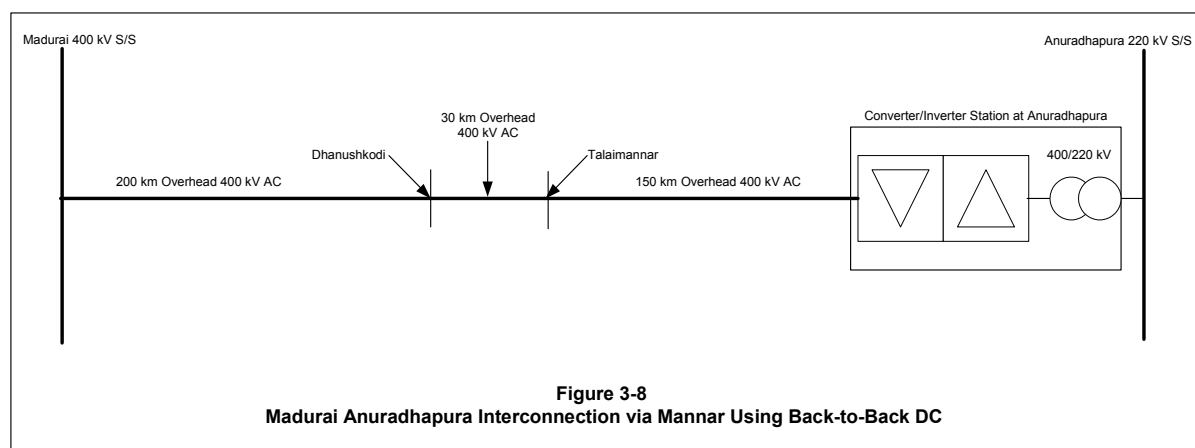
3.1.5 ALTERNATIVE MAI-BBDC: MADURAI-ANURADHAPURA INTERCONNECTION VIA MANNAR USING BACK-TO-BACK DC

A fourth alternative for the proposed interconnection also has been investigated. This alternative presents a simpler approach to transmission interconnection between the two countries in an attempt to capture both the simplicity and extensive experience in AC transmission with back-to-back DC. The technology of AC interconnection is well established with many of years of construction and operating experience.

A unique aspect of this alternative is the need to build an overhead transmission line segment across the 30 km stretch of the sea between Dhanushkodi and Talaimannar. The major portion of this stretch of sea is very shallow, and experience suggests that 30 meters to 60 meters deep pile foundation may be required for building transmission towers in this region.

Figure 3-8 shows the line diagram for Alternative **MAI-BBDC**, which would locate the interconnection terminus points at the Madurai and Anuradhapura substations. Implementation of this alternative would require the following:

- A 400 kV AC transmission line from the Madurai substation to the Anuradhapura 220kV substation. The line consists of the following segments:
 - Madurai to Dhanushkodi over-land overhead line: (200 km)
 - Dhanushkodi to Talaimannar over-the-sea overhead line: (30 km)
 - Talaimannar to Anuradhapura over-the-land overhead line: (150 km)
- A back-to-back converter/inverter station at Anuradhapura substation
- A 400/220 kV transformer and a feeder line from the transformer to the Anuradhapura substation.



3.2 TECHNICAL ASSESSMENT

3.2.1 MADURAI-ANURADHAPURA INTERCONNECTION USING HVDC

A large number of power transmission systems throughout the World encounter the challenges of crossing of large bodies of water. In many of these situations, the challenges are mitigated using under-water HVDC interconnections. In addition to crossing large bodies of water, an HVDC transmission is the preferred choice when the transmission distance is so large that the losses in an AC link are excessive to make such a link economically attractive.

Unlike AC transmissions, which exhibit technical difficulties and reduced ability to transmit power when the transmission distance becomes very long and the interconnecting systems have different frequencies, there are no such technical difficulties to an HVDC line. Electrical losses in an HVDC link are also much lower than an AC link.

One of the fundamental properties of an HVDC transmission is its asynchronous nature. The networks connected to the rectifier and to the inverter stations need not be in synchronism with each other. Interconnecting two grids by HVDC therefore allows them to retain individual frequency control. A disturbance in one of the AC systems that results in a frequency change will not affect the power transmitted via the link (unless the control system has been so designed), and there is no risk that the interconnection will become unstable.

An HVDC link requires two converter stations, one connected to each AC network. They are interconnected by an overhead DC transmission line or by a submarine DC cable or a combination of the two. One of the converter stations operates as a rectifier (taking power from the AC network) and the other as an inverter (delivering power from the DC side to the network).

Many overhead HVDC transmissions lines are built in a bipolar configuration, i.e. with one positive and one negative pole, which is considered for Variation 1. A bipolar configuration offers the highest reliability as such a configuration can actually serve as a two-path system (2x250 MW), since each pole can operate as an independent path when the other pole is unavailable. Each path in that case would carry half of the total power.

It is also possible to interconnect two systems in a monopolar configuration, which is considered for Variation 2. In this case, one DC path would carry full power. A major disadvantage of the monopolar configuration is that in case of a fault with any of the converter/inverter or conductor/cable, the full power is lost, and this may adversely affect the operation of the Sri Lankan system, which is much smaller than the Indian system. A bipolar system on the other hand provides a greater reliability as it is essentially two independent systems operating in parallel.

A monopolar system can be configured in three ways depending on the configuration of the return current path. If the entire interconnection is land-based, there is no need for a return conductor since the earth acts as the return current path. If the interconnection includes a water path, water can be used as a return conductor. But for environmental reasons, this is not done. Instead a return conductor is used. The third way is to provide a deep electrode station, well below the bottom of the water level, on each end of the interconnection. This avoids the need for a return conductor as well as avoids the use of water as the return current path.

Variation 3, the third variation of Alternative **MAI-HVDC**, does not involve any under-sea cable. Technically, Variations 1 and 3 are similar. Building an overhead line across the shallow sea for Variation 3 is primarily an economic issue.

3.2.2 TUTICORIN-PUTTALAM HVDC INTERCONNECTION

Alternative **TPI-HVDC** offers a transmission link whose entire transmission link (215 km) would be under the sea. One disadvantage of this is that there is no experience of such a long distance under-sea submarine cable construction. Technically, Variations MAI-HVDC 1 and TPI-HVDC 1 are similar. Likewise, Variations MAI-HVDC 2 and TPI-HVDC 2 are similar.

3.2.3 MADURAI-PUTTALAM HVDC INTERCONNECTION

We have seen that Alternative MAI-HVDC requires the shortest under-sea submarine cable, while Alternative TPI-HVDC requires the longest under-sea cable. Alternative MPI-HVDC offers a compromise between Alternative MAI-HVDC and Alternative TPI-HVDC, i.e., the sea link is 100m wide. Technically, the three alternatives are similar.

3.2.4 MADURAI-ANURADHAPURA AC INTERCONNECTION VIA MANNAR USING BACK-TO-BACK DC

Alternative MAI-BBDC is proposed to utilize a well-established AC technology, which is much simpler. The two major problems that accompany AC technology are the synchronization and stable operation of the two power systems. The problems are in achieving a stable operation because the frequency fluctuation of the India's Southern Region is large. To overcome these problems, a back-to-back DC converter/inverter station at one of the two terminus points is proposed.

One major disadvantage associated with an AC interconnection is high transmission loss which is approximately 5 percent of energy transmitted, compared to less than 1 percent for DC transmission.

3.2.5 CONCLUDING OBSERVATION

The previous sections provide a description of the alternative interconnections between India and Sri Lanka. Additional systems analyses and studies such as stability studies and reliability studies would be required to assess the potential real system performance of each of these alternatives.

A bipolar HVDC interconnection has an advantage over a monopolar HVDC interconnection with respect to system availability. This is an operational and economic issue and has not been considered in this preliminary study.

The alternatives proposed do not pose any technical obstacle to an interconnection project that would provide system reliability and security benefits. These benefits include diversity of energy sources, the sharing of operating and planning reserves, and the ability to obtain supplemental energy during times of generating facility maintenance outages.

The proposed project will derive additional benefits by taking a long term view of the supply and demand balance of the two countries. Increased energy transfers between the countries will provide for diversity of supply sources and types and reduction of transmission losses.

The maximum benefit of the proposed projects will arise when the proposed transmission interconnection is fully integrated with generation and transmission expansion plans of the two countries. By introducing an interconnection between India and Sri Lanka, it will be possible to plan generation and transmission system expansion on a bilateral basis. Such planning will realize increased reliability, diversity of supply sources, reduced transmission losses, and economies of scale over national planning alone. The construction of the proposed project will provide the platform on which to build mutual cooperation and planning that will be to the economic benefit of these countries.

The alternatives analyzed in this study do not appear to pose any technical obstacle to build a transmission interconnection between India and Sri Lanka that would benefit the two countries.

The purpose of this section is to provide a first-order indicative estimate of investment costs for the alternatives discussed previously and to provide an indication of the relative economic merit of those alternatives.

This preliminary assessment provides only a general indication of the relative economic merit of the proposed interconnections. To assess the economic viability, a more detailed assessment should be performed; such a task would be the subject of the follow-on of this study.

4.1 INVESTMENT REQUIREMENTS

To estimate the indicative investment costs of the proposed interconnections, the data specific to each alternative were considered. They include the order-of-magnitude costs of new rectifier/inverter stations in India and Sri Lanka, overhead transmission lines, and submarine cable. In addition, the improvements needed at the existing substations to accommodate the interconnections also were included. These improvements include the addition of buses, circuit breakers, protection relays, communication and related equipment, and civil works as needed.

The costs presented here are preliminary and represent “order-of-magnitude” estimates. They do not have the benefit of a detailed estimate due to the pre-feasibility nature of this study. These estimates are based on various sources, including private communications and discussions with officials of Power Grid (PGC India), Central Electricity Authority (CEA, India), Power Trading Corporation (PTC, India), Ceylon Electricity Board (CEB), and reputable industrial transmission system component manufacturers such as ABB, as well as information contained in several reports, which are listed in the Bibliography. Based on these preliminary cost estimates, the investment requirements for the various alternatives were estimated. The estimated investment costs for these alternatives range from about \$116 million to about \$175 million. Table 4-1 and Figure 4-1 set out the estimated investment costs for each alternative.

Table 4-1 Estimated Investment Costs for Alternatives (\$ Millions)

Alternative	Variation 1 – Bipolar HVDC	Variation 2 - Monopolar HVDC	Variation 3 - Bipolar HVDC All Overhead	400kV AC with Back-to- Back DC
Madurai Anuradhapura HVDC Interconnection via Mannar	\$133	\$116	\$134	NA
Tuticorin Puttalam HVDC Interconnection	\$175	\$153	NA	NA
Madurai Puttalam HVDC Interconnection via Kalputiya	\$156	\$138	NA	NA
Madurai Anuradhapura 400kV AC Interconnection via Mannar	NA	NA	NA	\$140

NA- Not Applicable

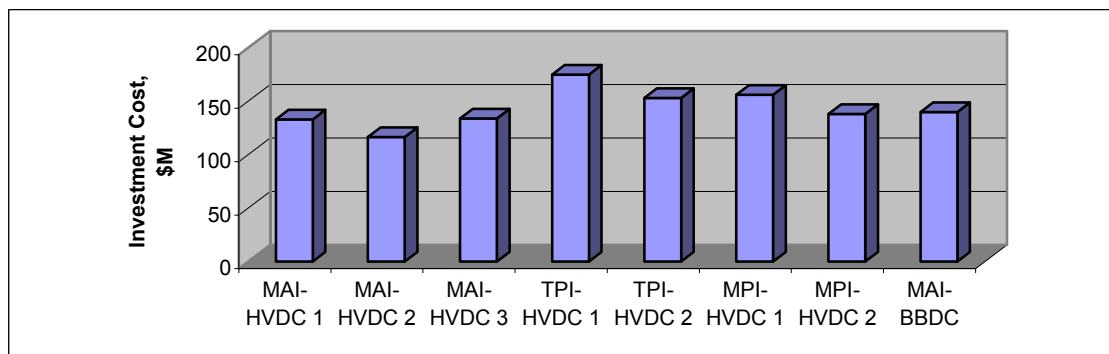


Figure 4-1 Estimated Investment Costs of Alternatives (\$ Millions)

Investment requirements for the Indo-Sri Lanka transmission interconnection Project are estimated to range from \$116 million to \$175 million, depending on the type of interconnection.

4.1.1 BIPOLAR HVDC INTERCONNECTIONS

Alternatives MAI-HVDC1, MAI-HVDC3, TPI-HVDC1, and MPI-HVDC1 would utilize the bipolar HVDC technology. Each of these alternative including the specific factors affecting the investment is discussed below.

Madurai-Anuradhapura interconnection using Bipolar HVDC via Mannar

In this alternative, the transmission line interconnection is all bipolar HVDC. It connects the Madurai substation in India with the Anuradhapura substation in Sri Lanka through Manar and crosses the sea from Dhanushkodi to Talaimannar. The investment cost of the alternative is estimated to be \$133M.

Madurai-Anuradhapura interconnection using Bipolar HVDC via Mannar (All Overhead)

Alternative MAI-HVDC3 has the same transmission route as Alternative MAI-HVDC1, and is all bipolar HVDC. However, in this alternative, the sea crossing is via an overhead line. The investment cost of the alternative is estimated to be \$134M.

Tuticorin-Puttalam interconnection using Bipolar HVDC

In this alternative, the transmission line interconnection is again all bipolar HVDC similar to Alternative MAI-HVDC1. It connects the Tuticorin substation in India directly with the Puttalam substation in Sri Lanka. This is the highest cost alternative (\$175M) as the entire transmission line is under the sea using submarine cable.

Madurai-Puttalam interconnection using Bipolar HVDC via Kalputiya

In this alternative, the transmission line interconnection is also all bipolar HVDC. It connects the Madurai substation in India with the Puttalam substation in Sri Lanka through Kalputiya. The cost of this investment is estimated to \$156M.

4.1.2 MONOPOLAR HVDC INTERCONNECTIONS

Alternatives MAI-HVDC2, TPI-HVDC2, and MPI-HVDC2 would utilize the monopolar HVDC technology. Each of these alternatives is addressed below.

Madurai-Anuradhapura interconnection using Monopolar HVDC

In this alternative, the transmission line interconnection is monopolar HVDC. As in Alternative MAI-HVDC1, it connects the Madurai substation in India with the Anuradhapura substation in Sri Lanka through Manar. The investment cost of the alternative is estimated to be \$116M, and is the lowest of all the alternatives.

Tuticorin-Puttalam interconnection using Monopolar HVDC

In this alternative, the transmission line interconnection is also all monopolar HVDC similar to Alternative MAI-HVDC2. It connects the Tuticorin substation in India directly with the Puttalam substation in Sri Lanka. The cost of this alternative (\$153M) is less than that of Alternative TPI-HVDC1 as it uses a monopolar configuration.

Madurai-Puttalam interconnection using Monopolar HVDC through Kalputiya

In this alternative, the transmission line interconnection is monopolar HVDC. As in Alternative MPI-HVDC1, it connects the Madurai substation in India with the Puttalam substation in Sri Lanka through Kalputiya. The cost of this investment is estimated to \$138.

4.1.3 AC INTERCONNECTION

Madurai-Anuradhapura interconnection using 400kV AC with Back-to-Back DC

Alternative MAI-BBDC is an all AC interconnection with back-to-back DC. It connects the Madurai substation in India with the Anuradhapura substation in Sri Lanka through Manar. The major advantage of this alternative is that it utilizes the well established AC transmission technology. A major disadvantage of this alternative is the relatively high cost (\$140M) due to the back-to-back DC units and overhead towers construction across the Palk Strait.

The relative advantages and disadvantages of the Alternatives are compared in Table 4-2.

Table 4-2: Relative Technical Advantages and Disadvantages of the Alternatives

Alternatives	Transmission Path	Technology	Advantages	Disadvantages
MAI-HVDC1	Madurai-Anuradhapura via Mannar	- Bipolar HVDC - Under-Sea Cable	- Highest reliability	- Moderate investment cost
MAI-HVDC2	Madurai-Anuradhapura via Mannar	- Monopolar HVDC - Under-Sea Cable	- Lowest investment cost	- Reliability lower than Alt. MAI-HVDC1
MAI-HVDC3	Madurai-Anuradhapura via Mannar	- Bipolar HVDC	- Highest reliability	- Moderate investment cost
TPI-HVDC1	Tuticorin-Puttalam	- Bipolar HVDC - Under-Sea Cable	- Highest reliability. - No clear advantage over Bipolar MAI-HVDC1	- Highest investment cost
TPI-HVDC2	Tuticorin-Puttalam	- Monopolar HVDC - Under-Sea Cable	- No clear advantage over monopolar MAI-HVDC2	- High investment cost
MPI-HVDC1	Madurai-Puttalam via Kalputiya	- Bipolar HVDC - Under-Sea Cable	- Bypasses Mannar-Anuradhapura corridor	- High investment cost
MPI-HVDC2	Madurai-Puttalam via Kalputiya	- Monopolar HVDC - Under-Sea Cable	- Bypasses Mannar-Anuradhapura corridor	- Reliability lower than Alt. MPI-HVDC1
MAI-BBDC	Madurai-Anuradhapura via Mannar	- AC with Back-to-Back DC	- Conventional Technology	- High Transmission Loss

4.2 ECONOMIC ASSESSMENT OF THE ALTERNATIVES

To assess the economics of the alternative transmission interconnections, two commonly used approaches are used.

The first approach—the Levelized Transmission Charge, sometimes known as wheeling charge — estimates the cost per kWh of power transmitted through the interconnection that is necessary to recover the investment cost of each alternative, plus provide an adequate return on the investment. The second approach—the cost of energy to the end user —estimates the delivered cost of energy consisting of the generating cost plus the transmission charge for each alternative as an indication of the expected range of cost of energy to the consumer. For this type of project, if the estimated range of imported cost of energy is on the same order of magnitude as the cost of energy from new generation by the consumer, then the project is judged to be worthy of serious consideration.

The following economic/financial parameters (generally applied in the industry) are used for the economic assessment of each of the alternatives:

- Debt/equity ratio 70/30
- Debt interest rate 13.5%
- Return on equity 16%
- Construction duration 3 years
- Loan term 9 years (post construction)
- Depreciable life 25 years
- Insurance 0.25% (on undepreciated assets)

- Working capital 1%
- Annual capital cost escalation 2%
- Annual O&M escalation 10%
- Startup year 2007

4.2.1 LEVELIZED TRANSMISSION COST

The levelized transmission cost provides one approach to assessing the relative merit of a project by looking at the fully burdened project cost on an annualized basis. Accordingly, based on this approach the levelized cost of the investments ranges from \$13 million per year to \$18 million per year. Year 2001 costs are used to derive these estimates. Figure 4-2 sets out the estimated levelized costs for each option.

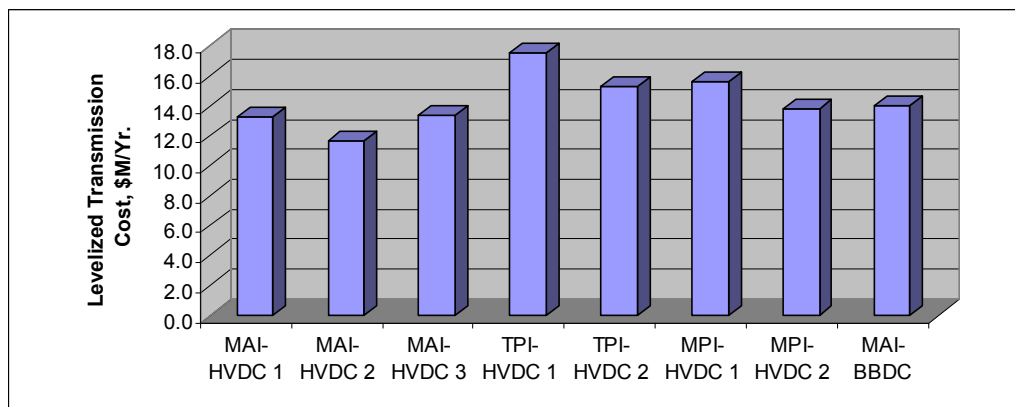


Figure 4-2: Levelized Transmission Costs of Each Alternative

Based on the above data, the levelized charge of transmission was estimated for various alternatives. These charge rates were based on 500MW transfer at 85% plant load factor. They range from 0.6 cents/kWh to 0.9 cents/kWh. Figure 4-3 illustrates the range.

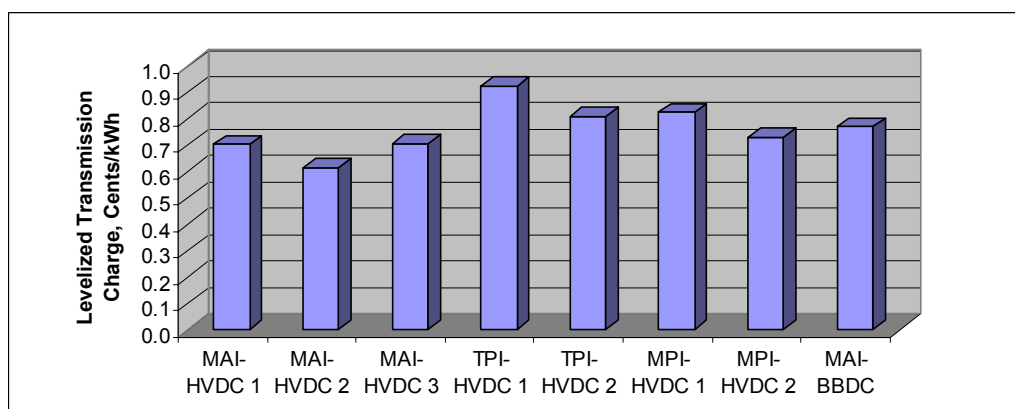


Figure 4-3: Levelized Transmission Charge (cents/kWh)

The transmission charge for the various alternatives varies from 0.6 cents/kWh to 0.9 cents/kWh.

Comparing the alternatives, Alternative MAI-HVDC 2 provides lowest transmission charge rate. It may also be noticed that the Alternatives MAI-HVDC 1, TPI-HVDC2, and MPI-HVDC provide approximately the same transmission charge rate.

4.2.2 ASSESSMENT BASED ON COST OF ELECTRICITY

An estimate of the range of cost of energy to the importer is another way to assess the relative economic merit of a project. This requires the knowledge of the cost of energy at the point of generation on the exporter's side and the cost of alternative sources of supply for the importer. This cost, added to the cost of transmission, would indicate the range of cost of energy that could be expected by the importer. For the purposes of this assessment, the costs of energy on both the exporter and importer side are assumed to be at the terminus points.

4.2.2.1 WHOLESALE ENERGY TARIFF IN INDIA

For the purpose of estimating the cost of energy to the importer, it is assumed that in the near term, power would be transferred from India to Sri Lanka. With this as an assumption, various agencies of India such as Central Electricity Authority, Power Trading Corporation, Power Grid Corporation were consulted to get an idea of the expected cost of generation at the terminus points of interconnection in India based on future generating plants. In addition, the generating costs of the existing plants in southern India as well as other regions of India were also reviewed. Based on the above, it was judged that the cost of energy at the terminus points in India would range from 5.8 to 6.8 cents per kWh.

4.2.2.2 WHOLESALE ENERGY TARIFF IN SRI LANKA

Sri Lanka is planning to rapidly introduce new generation plants. Various estimates exist for the cost of generation from coal-based and fuel oil-based projects. For projects financed by IPPs, these would generally fall in the range of 6.0 cents/kWh to 9.0 cents/kWh. The cost of transmission from these projects to the various load centers would range from 1.0 cent/kWh to 2.0 cents/kWh. The resulting wholesale energy tariff in Sri Lanka would be the sum of the cost of generation and the cost of transmission. This would range from 7.0 cents/kWh to 11.0 cents/kWh. This range reflects the kind of tariffs that would be required for projects to be developed by the private sector in Sri Lanka. However, since this range is higher than current tariffs, which generally fall below 6.0cents/kWh, it may be difficult to realize the high end of this range. Projects at the high end will probably not be developed in the near future. For this reason, a range of 7.0cents/kWh to 9.0cents/kWh is assumed for wholesale energy tariff in Sri Lanka, given the assumed timeframe of the proposed power exchange project.

4.2.2.3 EXPECTED DELIVERED COST OF ENERGY IN SRI LANKA

Based on the above premise, the range of delivered cost of energy in Sri Lanka is estimated by adding the range of generation cost in India and the range of transmission charge of the alternative interconnections. Thus the resulting delivered cost of energy in Sri Lanka is expected to range from 6.5 to 8.0 cents/kWh. The high cost for Alternative MAI-BBDC reflects high electrical losses in the AC transmission line. The range is illustrated in Figure 4-4.

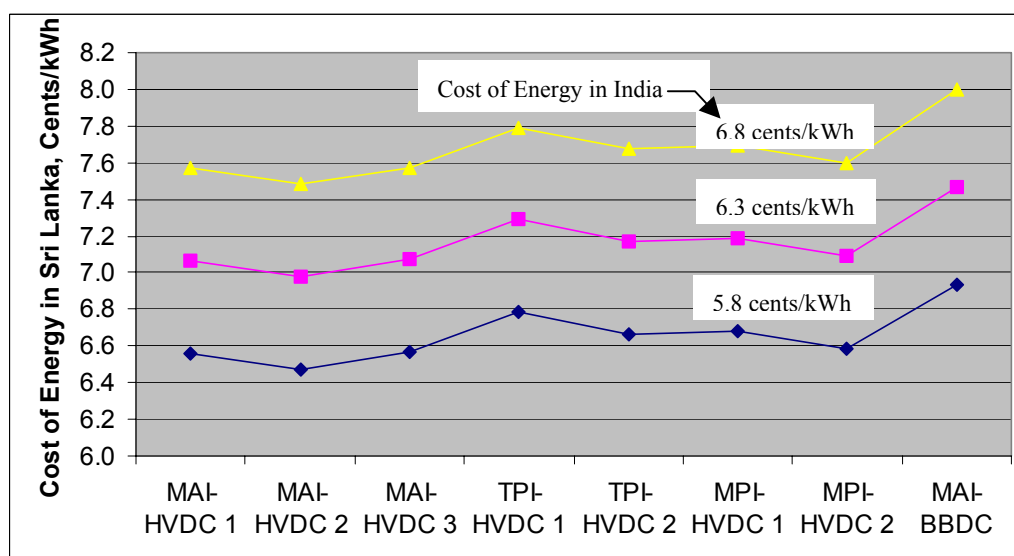


Figure 4-4 Expected Delivered Cost of Energy in Sri Lanka, Cents/kWh

Based on the above analysis, the following observations can be made:

The estimated delivered cost of energy in Sri Lanka is below the expected cost of new in-country generation. At the 500 MW level of power transfer, this cost of energy would range from 6.5 cents per kWh to 8.0 cents per kWh

4.3 CONCLUSIONS

The overall assessment (technical and economic) is illustrated in Table 4-3 below. The following can be concluded from the above preliminary analysis:

- The investment requirements for the alternative interconnections are moderate and should not present a significant barrier to the development of an interconnection.
- All these latter alternatives should be further evaluated in detail subsequent to this study to identify the preferred alternative.
- Alternative MAI-HVDC1 offers the highest reliability, and Alternative MAI-HVDC2 offers the lowest cost. Alternatives MPI-HVDC1 and MPI-HVDC2 offer a unique feature: they bypass the long land route in Sri Lanka, and connect directly to the major load center of the country.
- Tuticorin-Puttalam HVDC and Madurai-Anuradhapura Back-to-Back alternatives are the most expensive. These alternatives do not offer any additional technical advantage over the others.
- Bipolar vs. Monopolar – Bipolar offers higher reliability over monopolar. This has not been factored in the assessment.

Table 4-3: Relative Overall Advantages and Disadvantages of the Alternatives

Alternatives	Transmission Path	Technology	Advantages	Disadvantages
MAI-HVDC1	Madurai-Anuradhapura via Mannar	- Bipolar HVDC - Under-Sea Cable	- Highest reliability - Medium Cost of Electricity	- Moderate investment cost
MAI-HVDC2	Madurai-Anuradhapura via Mannar	- Monopolar HVDC - Under-Sea Cable	- Lowest investment cost - Lowest Cost of Electricity	- Reliability lower than Alt. MAI-HVDC1
MAI-HVDC3	Madurai-Anuradhapura via Mannar	- Bipolar HVDC	- Highest reliability - Medium Cost of Electricity	- Moderate investment cost
TPI-HVDC1	Tuticorin-Puttalam	- Bipolar HVDC - Under-Sea Cable	- Highest reliability. - No clear advantage over bipolar MAI-HVDC1	- Highest investment cost - High Cost of Electricity
TPI-HVDC2	Tuticorin-Puttalam	- Monopolar HVDC - Under-Sea Cable	- No clear advantage over monopolar MAI-HVDC2	- High investment cost - High Cost of Electricity
MPI-HVDC1	Madurai-Puttalam via Kalputiya	- Bipolar HVDC - Under-Sea Cable	- Bypasses Mannar-Anuradhapura corridor	- High investment cost - High Cost of Electricity
MPI-HVDC2	Madurai-Puttalam via Kalputiya	- Monopolar HVDC - Under-Sea Cable	- Bypasses Mannar-Anuradhapura corridor	- Reliability lower than Alt. MPI-HVDC1 - High Cost of Electricity
MAI-BBDC	Madurai-Anuradhapura via Mannar	- AC with Back-to-Back DC	- Conventional Technology	- High Transmission Loss - Highest Cost of Electricity

In this study report, a number of potential alternatives have been identified. A detailed assessment would be needed in detailed feasibility study to identify the preferred alternative.

This study report, has attempted to identify and analyze the potential alternatives for interconnecting the transmission systems of India and Sri Lanka. The purpose of the analysis is to perform a preliminary technical and economic assessment of the alternative interconnections. The assessment included:

- characterizing technical requirements
- developing indicative investment requirements, and
- estimating indicative delivered cost of electricity

The assessment would then serve as the basis for more detailed analysis of a specific alternative. Based on this preliminary assessment, the following conclusions and recommendations emerge:

5.1 CONCLUSIONS

- Presently, no bilateral power exchange exists between India and Sri Lanka
- Proposed power exchange would serve as a supply/generation option for Sri Lanka
 - Sri Lanka has developed a generation plan through the year 2014
 - The proposed transmission interconnection scheme would provide Sri Lanka with an additional option in its planned generation mix
- The transmission systems under development in the two countries would support power exchange between the countries
- Based on expected supply/demand scenario, India should be able to supply the required power to Sri Lanka
- A number of technically viable alternatives were identified to interconnect the grids of India and Sri Lanka. The terminus points in India would be located at either the Madurai or Tuticorin substations, both in the State of Tamil Nadu in India. In Sri Lanka, the terminus points would be at either Anuradhapura or Puttalam. The alternatives are:
 - **Alternative 'MAI-HVDC':** Madurai-Anuradhapura Interconnection using HVDC;
 - **Alternative 'TPI-HVDC':** Tuticorin-Puttalam Interconnection using HVDC;
 - **Alternative 'MPI-HVDC':** Madurai-Puttalam Interconnection using HVDC;
 - **Alternative 'MAI-BBDC':** Madurai-Anuradhapura Interconnection using HVAC with back-to-back DC.
- Tuticorin-Puttalam HVDC and Madurai-Anuradhapura Back-to-Back DC alternatives are the most expensive. These alternatives do not offer any additional technical advantage over the others.
- Bipolar vs. Monopolar – Bipolar offers higher reliability over monopolar. This has not been factored in the assessment.
- The alternatives permit power exchange of up to 1,000 MW
- Indicative investment requirement for these alternatives ranges from approximately \$116 million to \$175 million
- Indicative levelized transmission costs for the alternatives range from 0.6 to 0.9 cents per kWh for transfer of 500 MW

- Indicative delivered cost of energy to Sri Lanka from the alternatives ranges from 6.5 to 8 cents/kWh. This is at or below the expected cost of internal generation, which is estimated to range from 7 to 9 cents/kWh.

5.2 RECOMMENDATIONS

- Tuticorin-Puttalam HVDC and Madurai-Anuradhapura Back-to-Back DC alternatives are the most expensive. These alternatives do not offer any additional technical advantage over the others.
- Bipolar vs. Monopolar – Bipolar offers higher reliability over monopolar. This has not been factored in the assessment. This aspect needs to be evaluated in detailed feasibility study.
- The cost estimates are preliminary and should be developed in more details in later Phase of the detailed study.
- Institutional and other issues such as desirability of overhead transmission towers across Palk Strait should be considered.
- Location of interconnecting substation in Sri Lanka should be given proper consideration. The delivered cost of imported power from India would depend on the transmission distance of the load center from the interconnecting substation.

In this study, a preliminary technical and economic assessment of several transmission interconnection alternatives was performed. The identified alternatives would provide significant system reliability improvements, increased diversity of supply, improved security of supply, reduced line losses, shared operating and spinning reserves, and shared emergency power.

In detailed Feasibility study, a detailed technical and economic assessment will be performed and a preferred interconnection concept will be identified and proposed for implementation. The proposed interconnection would serve as an important “ice breaker” that demonstrates - in practice - how regional cooperation in energy can be carried out to serve the mutual benefits of the participating countries.

Over the longer term, the proposed interconnection would provide greater promise. An interconnected transmission grid could expand its capacity to allow substantial power trade at significantly lower cost and reduced environmental impacts by achieving greater economies of scale.

To achieve these benefits and to make the proposed regional interconnection a reality, it is recommended that, during the detailed Feasibility study, a Working Committee be established consisting of stakeholders representing India and Sri Lanka to:

- Develop and execute a Memorandum of Understanding for regional transmission system operators that would establish the operating principles for the proposed interconnection including the rights and obligations of participants and the procedures for ensuring full cost recovery and equitable sharing of benefits.
- Serve as a liaison with energy ministries and other government and private sector entities for development and implementation of the proposed interconnection.
- Oversee the preparation of a detailed project report for the World Bank and the Asian Development Bank that satisfies all of the technical, economic and legal/regulatory requirements for developing, financing, and implementing the proposed interconnection.
- Coordinate activities with an environmental assessment team to address environmental issues associated with this proposed interconnection.
- In accomplishing its purposes, the Working Committee or Subcommittee should serve as a regional advisory body to direct the related technical assistance that is being provided under the SARI/Energy project, as it would specifically support implementation of the proposed interconnection. Activities that could be supported under this project include:
 - Review the energy supply/demand balance that is being prepared in support of the proposed interconnected grid; confirm the amount and cost of power available for power transfer and trade under the recommended alternative, which would be identified in detailed Feasibility study.
 - Validate the recommended interconnection alternative and perform a detailed integrated resource assessment in order to quantify the costs and benefits.

- Identify and select favored alternatives for establishing open transmission access, fair pricing and conditions of service for inclusion in a transmission services agreement.
- Review legal and regulatory requirements to support development of the proposed interconnection, including a review of existing laws and regulations in both the countries, and provide assistance to draft any necessary changes/additions in rules, regulations, and laws.
- Provide assistance to establish a regulatory regime that would support development of the proposed interconnection by coordinating existing or proposed independent regulatory entities in each country.
- Support development of an initial environmental impact assessment to collect data, assess impacts, and develop mitigation measures that would be implemented through an environmental management plan.

Bibliography

Long Term Generation Expansion Plan, 2000-2014, Ceylon Electricity Board, May 2000.

Statistical Digest 2000, Ceylon Electricity Board.

National Physical Planning Policy, National Physical Planning Department, Sri Lanka, Nov. 2001.

Power Transmission in India, S.C. Misra, Director (Projects), Power Grid Corporation of India Ltd.

HVDC information materials from M/s ABB, Sweden, Dec. 2001

Presentation made by Mr. Birger Jonsson of M/s ABB and his team to the Nexant team on Dec. 3, 2001 in their offices at New Delhi, India, Dec. 2001

Technical/commercial assessment of submarine HVDC Projects. Private communication with Mr. R.S. Mony and Mr. Somnath Chakraborty of M/s ABB, New Delhi, Dec. 2001

Briefing on Power Transmission in India, Mr. V. Ramakrishna, Chief Engineer (Transmission) and Mr. A.K. Asthana, Director, Central Electricity Authority, New Delhi, Dec. 2001

SEBs' report 2001 from Powerline, New Delhi. Data on Tamil Nadu power sector scenario in India, Dec. 2001

Briefing on All India Power Scenario, Private communication with Mr. G.L. Mittal, Chief Engineer, Central Electricity Authority in India, New Delhi, Dec. 2001

Discussions on study for Transfer of Power from India to Sri Lanka, PowerGrid Corporation of India Ltd, New Delhi “Systems Engineering and Feasibility Group.”, Dec. 2001

Private Communication on HVDC Technology - latest developments with with Mr. V.K. Parashar, Executive Director (Engg-HVDC), PowerGrid Corp. of India Ltd. New Delhi, Dec. 2001

Cross Border Power Interconnections and operating guidelines – Private Communication with Mr. Bhanu Bhushan, Director (Operations), PowerGrid Corp. of India Ltd., New Delhi, Dec. 2001

Feasibility of overhead cable/wire interconnection in the sea – Private Communication with Mr. D. Chowdhary, AGM (Tower Designs – Engg) PowerGrid Corp. of India Ltd., New Delhi, Dec. 2001

Briefing on Energy Trading mechanism/Energy Market – Mr. T.N. Thakur, CMD, Power Trading Corp. of India Ltd., New Delhi, Dec. 2001

Potential of Power Trade from Tamil Nadu – Private Communication with Mr. O.P. Maken, Vice-President (Projects) of Power Trading Corp. of India Ltd., New Delhi, Dec. 2001

Private Communication with Ceylon Electricity Board, Sri Lanka, Dec. 2001:

- a. Mr. Abeygunawardena, DGM, Generation (Planning) and his team
- b. Mr. Abeysekara, DGM, Transmission (Planning) and his team
- c. Mrs. Mendis, DGM, Systems Control, and her team

Private Communication with Mr. D. Chandrashekhar, Project Director, Ceylon Petroleum Corp., Sri Lanka, Dec. 2001

Private Communication with Mr. Jayasekara, Physical Planning Dept., Sri Lanka, Dec. 2001

Private Communication with NARA and other team members, Dec. 2001

Private Communication, Dr. Tilak Siyambalapitiya, Private Consultant, Colombo, Sri Lanka, Dec. 2001.

The voltage of the HVDC line can be selected freely to provide the lowest overall cost, and it need not be coordinated with any of the AC system voltages. The highest DC voltage in use is $\pm 600\text{KV}$. A large number of HVDC transmissions in the 1200---3000 MW range operate at $\pm 500\text{KV}$.

Most of the recent HVDC transmissions involving lines or cables have a rated capacity of 300MW or higher, since the cost per KW of the converter stations increases substantially at lower ratings. The cost per KW of back-to-back stations would, however, remain low down to 100MW or below.

The possibility to control the level of active power transmitted is one of the fundamental advantages with HVDC. This control is done electronically by the control systems included in the two converter stations. Often the main control mode is based on constant power transfer, i.e. the operator orders the link to transmit the amount of power to be exchanged. However, in many cases the control systems of the link are designed to provide additional control action to improve the AC system performance.

One such control alternative often used in HVDC links interconnecting different power systems is to let the link automatically change the ordered power level to assist a network experiencing a problem, such as the loss of major generating unit.

Due to the fact that the power of the DC link is always controlled and limited so as not to exceed the link's capacity, there is never a risk that the interconnection will get overloaded and trip out when best needed. An HVDC link would also prevent disturbances occurring in one of the interconnected grids from spreading into the other. The worst that could happen is that the power flow on the HVDC interconnection would cease in case one of the grids gets so disturbed, that it is unable to deliver or receive power.

To enable power transmission from one network to another that is geographically close, it is not uncommon to make arrangements that change the border between the two grids. Such measures are normally seen as temporary to overcome a critical supply situation in one of the networks or to take advantage of a temporary surplus and enable export of low cost power. It has also been used to honor power purchase agreements before a permanent interconnection facility is in place.

The main advantage with this method is that power exchange can be arranged on very short notice provided that a (normally open) transmission line exists between the grids. The disadvantage is that a limited part of one of the systems has to be isolated from the rest of that system, which makes it necessary to open some circuits that normally would be closed to provide redundant paths for the power flow inside the network. The reliability of the remaining system may therefore be degraded. This method is arranging power transmission between two systems is also very inflexible. It may be difficult to achieve the desired power export/import levels and power direction cannot be changed.

In most cases, where the method has been used, a particular generating station close to the border is disconnected from the surrounding grid and connected via one or a few lines to the

other network. The feasibility of this is very dependent on the existence of a suitable generating station and the network topology.

Another way would be to isolate a certain load area in the receiving grid and feed it from the neighboring network. The latter would probably in most cases be even more difficult to arrange due to the fact that not only a single power station but a suitable large distribution grid area has to be identified and separated. One additional drawback with this method is that the load area would in most cases be supplied via a single radial connection from the other grid. If that connection carries the whole or large part of the load, a single contingency outage would cause a blackout.

Due to these inconveniences, the above methods to achieve power transfer between two grids are normally regarded as temporary measures. If a long term need for power exchange can be identified it is likely that a permanent AC or DC interconnection would make sense.

Factors that are important in the selection of technology for a power system interconnection and that will have to be studied carefully are:

- Power capacity of the interconnection
- Need for stage-wise buildup of interconnection capacity
- Connection points in each grid and need for intermediate substations
- Reliability requirements/number of circuits
- Transient stability of the interconnected system following disturbances
- Investment costs of the studied alternatives
- When the preferred technology has been selected, several system studies and design studies will have to be made to define it in greater detail.

